Volume 13 OCTOBER 1929 Number 10

BULLETIN
of the
American Association *of* Petroleum Geologists

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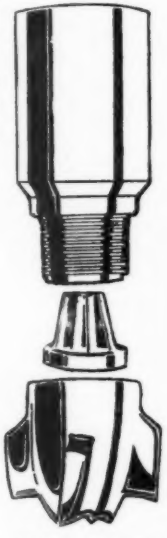

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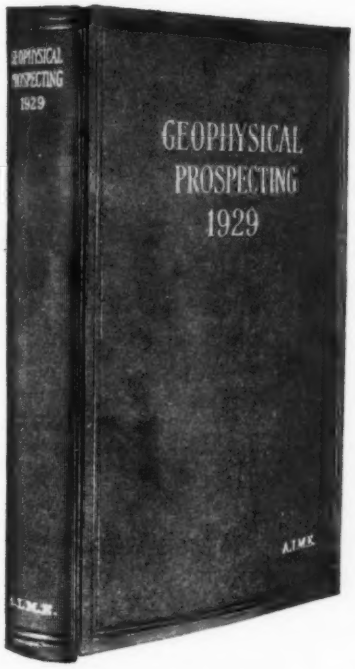

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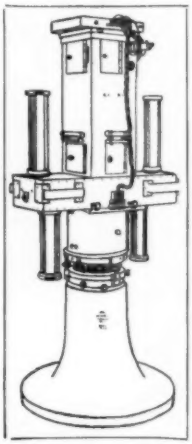

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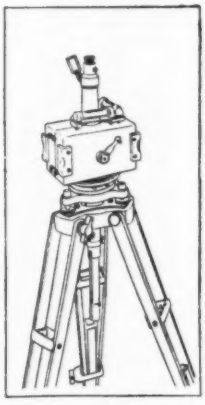

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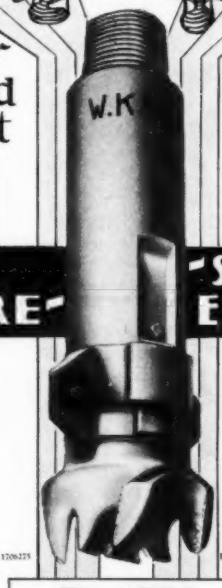

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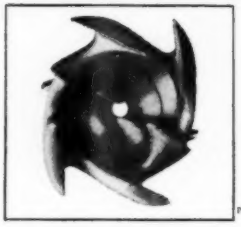

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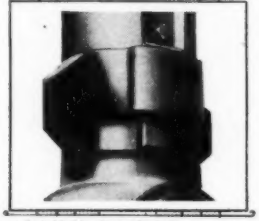

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The subscription price to non-members of the Association is $15.00 per year (separate numbers $1.50) prepaid to addresses in the United States. For addresses outside the United States, an additional charge of $0.40 is made on each subscription to cover extra wrapping and handling.

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OCTOBER 1929

CARBON RATIOS AND OIL GRAVITIES IN THE ROCKY MOUNTAIN REGION OF THE UNITED STATES[1]

C. E. DOBBIN[2]
Denver, Colorado

ABSTRACT

In the Rocky Mountain region, oil ranging in gravity from 13° to 75° Bé. occurs in commercial quantities in formations ranging in age from Carboniferous to Tertiary. Although the Carboniferous oils are predominantly low in gravity and the post-Carboniferous oils high in gravity, there is a great variation in the character of the oil in the same formation in different fields and in different formations in the same field. It is evident that the quality of the Carboniferous oil bears no demonstrable relation to the dynamic metamorphism which the region has locally undergone.

Carbon ratios as ordinarily calculated do not show satisfactorily the rank of the low-rank Cretaceous and Tertiary coals found in the Rocky Mountain region, and are a very doubtful measure of the dynamic metamorphism the coals and enclosing strata have undergone.

ACKNOWLEDGMENTS

The writer is under obligation to W. T. Thom, Jr., of Princeton University, for criticism of the manuscript; to Mrs. A. K. Henderson and to E. T. Vincent of the U. S. Geological Survey for help in calculating the carbon ratios and preparing the illustrations, respectively; and to E. W. Krampert of the Prairie Oil and Gas Company for supplying the gravities of the oils in the southern Wyoming fields.

To those named, as well as to the engineers of the United States Geological Survey and the several Rocky Mountain geologists who supplied data and reviewed the illustrations, the writer wishes to express his grateful appreciation.

[1]Read before the Association at the Fort Worth meeting, March 22, 1929. Manuscript received by the editor, May 11, 1929. Published with the permission of the director, U. S. Geological Survey.

[2]Geologist, U. S. Geological Survey.

INTRODUCTION

The purpose of the writer is to set forth briefly some of the relations between the occurrence and grade of oil and gas and the degree of alteration of the enclosing strata in part of the Rocky Mountain region, in which the structural conditions of oil and gas accumulation, the age and character of the coals, and the age of the oil-bearing formations are different from those in other areas containing widespread coal and oil fields to which the carbon-ratio theory has been applied. In the Rocky Mountain region there are approximately 50 known oil fields, 30 commercial gas fields, and many areas containing lignitic to medium-rank coal. Consequently the region presents an excellent opportunity for determining whether the carbon ratios of the younger low-rank coals bear significant relation to the character and presence of petroleum and gas, as seems to be true where higher-rank Paleozoic coals are concerned.[1] The oil-bearing formations in the Rocky Mountain fields range in age from Mississippian to Eocene, whereas, with few exceptions,[2] the published papers on carbon ratios have almost exclusively dealt with areas containing only Carboniferous coals and Carboniferous or older oils. The utility of the carbon-ratio theory as a guide to oil occurrence in the Rocky Mountain fields of Canada has been challenged by Jones,[3] and the validity of his contention may well be tested by a review of the plentiful evidence afforded by the coal and oil fields south of the Canadian line. The problem in hand may be resolved into several distinct parts:

(1) The character of the oils found in the Rocky Mountain fields, and the causes of the variations of Baumé gravity shown by oils occurring (a) in the same sand but in different fields, and (b) in different sands in the same field;

(2) The lateral and vertical variations in carbon ratios displayed by coals occurring in proximity to the several oil fields, and the bearing of factors other than ordinary (chiefly dynamic) metamorphism upon the carbon ratios given by the analyses;

[1] D. White, "Some Relations in Origin Between Coal and Petroleum," *Jour. Washington Acad. Sci.*, Vol. 5 (1915), pp. 189-212.

[2] Willis Storm, "Carbon Ratios of Cretaceous Coals in New Mexico in their Possible Relation to Oil," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8 (1924), pp. 519-23.
G. S. Hume, "Carbon Ratios of Coal as an Index of Oil and Gas Prospects in Western Canada," *Bull. Canadian Inst. Min. and Met.* (March, 1927), pp. 325-45.
I. W. Jones, "Carbon Ratios as an Index of Oil and Gas in Western Canada," *Econ. Geol.*, Vol. 23 (1928), pp. 353-80.

[3] *Op. cit.*

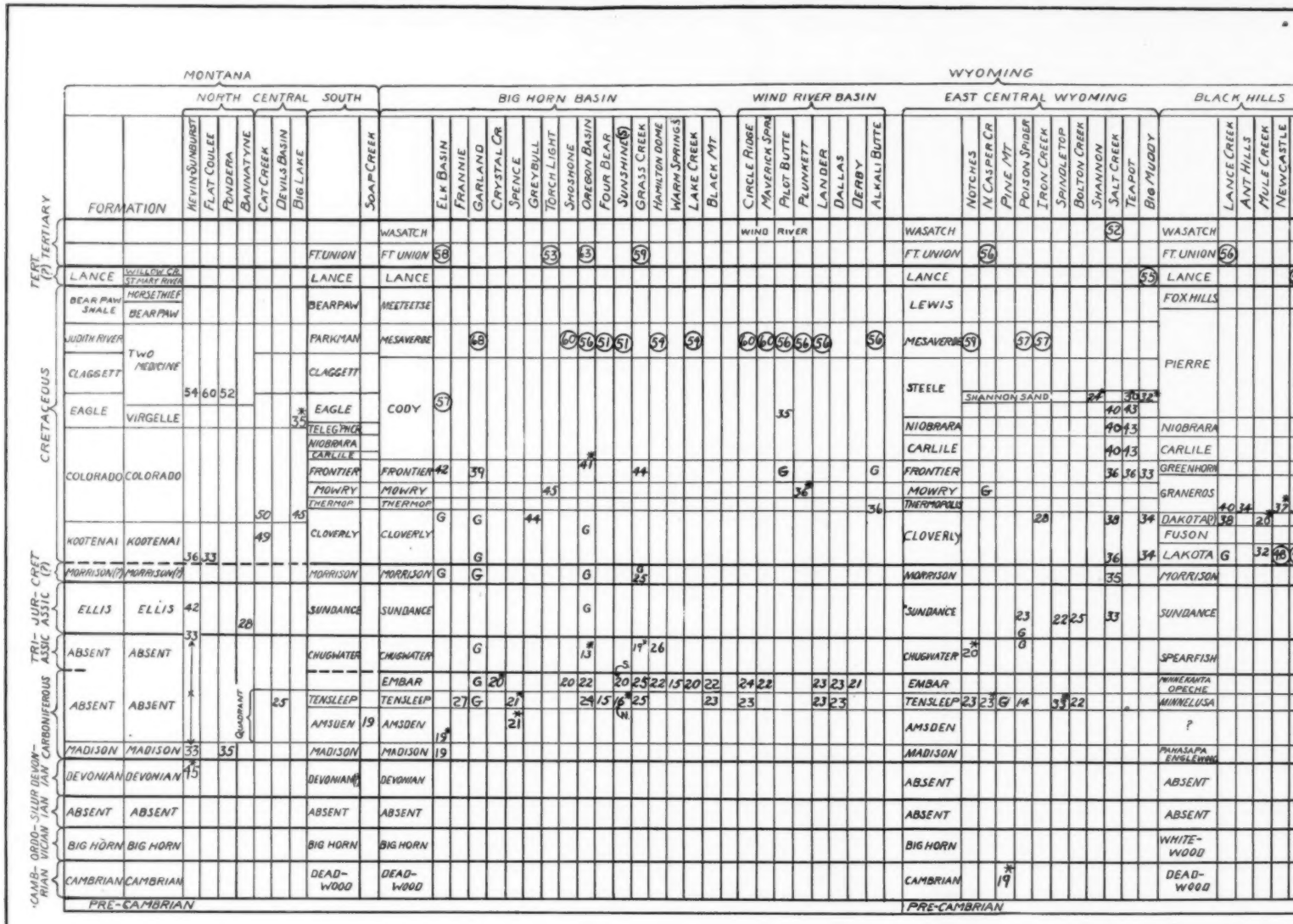


CHART SHOWING THE GRAVITY OF THE OIL PRODUCED FROM THE VARIOUS F
THE CARBON RATIOS OF THE COALS.

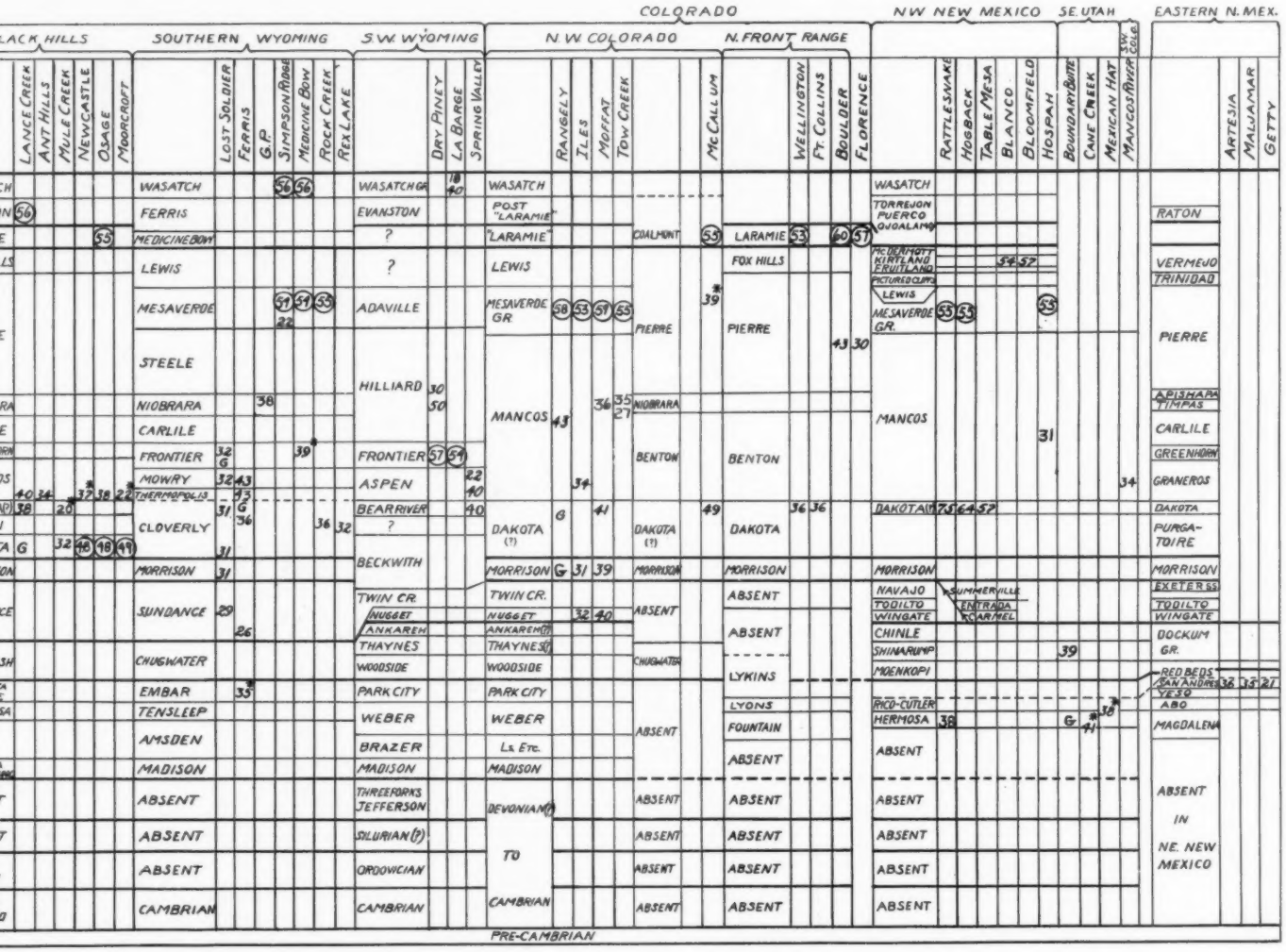
EXPLANATION

33-GRAVITY OF OIL (BAUME S

33*-NON-COMMERCIAL

G-GAS

(53)-CARBON RATIOS



VARIOUS FORMATIONS IN THE ROCKY MOUNTAIN OIL FIELDS AND

ON

L (BAUME SCALE)

IAL

OS

(3) The bearing of the facts developed under (1) and (2) in terms of the applicability and utility of the carbon-ratio theory where low-rank Cretaceous and post-Cretaceous coals are concerned.

GRAVITY (BAUMÉ) OF ROCKY MOUNTAIN OILS

The Carboniferous oils in the Rocky Mountain region are predominantly low-gravity black oils with an asphaltic base, the average gravity being about 23° (Plate 12). The important exception to this almost consistent low gravity is the 34° gravity oil found in the top of the Madison limestone of Mississippian age in the Pondera and Kevin-Sunburst fields, Montana, and the 30° gravity oil found in the Hermosa formation of Pennsylvanian age in the Rattlesnake field, New Mexico. Small amounts of light oil have also been found in Carboniferous rocks in the Ferris and other fields in central Wyoming and in the Cane Creek and Mexican Hat fields in southeastern Utah.

Triassic beds produce commercial amounts of oil in only one field in the Rocky Mountain region, namely, the Hamilton dome in the Big Horn Basin, Wyoming, where the Chugwater formation yields oil of 26° gravity. The Chugwater contains some 13° gravity oil in the Oregon Basin field, Wyoming, and the Shinarump conglomerate has yielded some 39° gravity oil in southeastern Utah. Elsewhere in the region the Triassic beds are locally saturated by heavy oil.

The Jurassic formations produce both light and heavy oil at widely separated points in the Rocky Mountain region. Oil ranging in gravity from 28° to 42° is found in the Ellis formation in the Sweetgrass arch fields, Montana, whereas black oil with an average gravity of 22° occurs in its almost equivalent formation, the Sundance, in the Poison Spider, Spindletop, and Bolton Creek fields in central Wyoming. In the Salt Creek field, only 45 miles northeast of the Poison Spider field, the Sundance produces 33° gravity oil and in the Iles and Moffat pools in northwestern Colorado the Nugget sandstone produces oil ranging in gravity from 32° to 40°.

The Cretaceous formations (including the Cretaceous(?) Morrison) produce oil averaging 41° gravity in Montana, 36° in Wyoming, 36° in Colorado, and 56° in New Mexico. The Rattlesnake field in northwestern New Mexico produces 75° gravity oil from the Dakota(?) sandstone at the base of the Upper Cretaceous, and the Blanco and Bloomfield districts near by yield oil of about 56° gravity from the Farmington sandstone member of the Kirtland shale, which lies almost at the top of the Cretaceous. Interestingly enough, the intermediate Tocito sandstone

lentil of the Mancos shale contains 31° gravity oil in the Hospah field, a relatively short distance southeast. That not all the Cretaceous oil in the Rocky Mountain region is high in gravity may perhaps be shown by the occurrence of 24° gravity oil in the Shannon pool at the north end of the Salt Creek field, 22° gravity oil in the old Moorcroft field, and 22° gravity oil in the Simpson Ridge field, all in Wyoming. More probably the low gravity of these Cretaceous oils is due to the shallow depth at which they occur.

Commercial quantities of oil have been found in the Tertiary rocks of the Rocky Mountain region only in the Labarge field in southwestern Wyoming, where oil ranging in gravity from 18° to 40° is produced from a horizon in the Wasatch group of Eocene age.

VARIATIONS IN GRAVITY OF OIL IN DIFFERENT HORIZONS IN ONE FIELD

Besides showing a wide variation in the gravity of the oil in one formation at widely separated points in the Rocky Mountain region, Plate 12 shows that in some cases there is a large difference in the gravity of the oil in different formations in one field. In the Oregon Basin field, Wyoming, the Upper Cretaceous Frontier formation contains some 41° gravity oil, the Triassic Chugwater formation some 13° gravity oil, and the Carboniferous Embar and Tensleep formations large amounts of 23° gravity black oil. In the Grass Creek field, Wyoming, the Frontier oil is 44° gravity, the Cretaceous(?) Morrison oil 25° gravity, and the Embar-Tensleep oil 25° gravity. In the Salt Creek field, Wyoming, the Upper Cretaceous Shannon sandstone contains 24° gravity oil, whereas the gravity of the oil from several other Cretaceous horizons ranges from 35° to 40° and that from the Jurassic Sundance formation is 33° gravity. In the Ferris field, Wyoming, the Upper Cretaceous Mowry shale, which some think is the source of a large amount of the Rocky Mountain oil, contains 43° gravity oil, the Jurassic Sundance formation 26° gravity oil, and the Carboniferous Embar formation a little 35° gravity oil.

The occurrence of black oil with an average gravity of 23° in Carboniferous limestone below light oil in Cretaceous sandstones in several of the Rocky Mountain fields may be due to differences in origin; to weathering of the Carboniferous oil in pre-Triassic or Jurassic times; to a natural process of refining or filtration; or to deterioration as a result of contact with sulphate-bearing waters. Whichever conclusion is accepted, it is evident that the quality of the Carboniferous oil bears no demonstrable relation to the dynamic metamorphism which the region has locally undergone. The variations in the character of the Cretaceous oil found at the same horizon at widely separated places in the region

are probably due to differences in the composition of the original organic deposit or to elimination in certain places of heavier hydrocarbons through filtration incident to transverse migration.

AGE, DISTRIBUTION, AND CARBON RATIOS OF ROCKY MOUNTAIN COALS

The coals in the Rocky Mountain region are of Cretaceous and Tertiary ages (Plate 12 and Figs. 1 and 2) and generally occur in basins which lie between mountainous uplifts, the prominent exceptions being those in the plains region of eastern Montana, and those east of the Front Range in Colorado. That the coals increase progressively in rank with age (also locally under greater dynamic metamorphism, that is, toward the major uplifts) and have locally been metamorphosed to anthracite by igneous intrusions, is broadly evident throughout the region. That carbon ratios as reported in ordinary analyses do not indicate the rank of low-rank coals is well shown by comparing, for example, the carbon ratios of the high-moisture-bearing Tertiary lignites and low-rank sub-bituminous coals of eastern Montana (50-57) with those of the higher-rank sub-bituminous Tertiary coals occurring a few miles east of the Big Horn Mountains near Sheridan, Wyoming (55), and with the Cretaceous bituminous coals mined near Rock Springs and Kemmerer in southwestern Wyoming (54-63). In fact some of the Tertiary sub-bituminous coals in this region have carbon ratios in excess of 60 (Plate 12 and Figs. 1 and 2).

That the carbon-ratio theory, as developed in eastern areas containing high-rank Carboniferous coals, can not be indiscriminately applied to the Rocky Mountain region, where the coals are low in rank, is shown, for example, by the occurrence of low-gravity Carboniferous oils in areas of relatively high carbon ratios in the western and southern parts of the Big Horn Basin, Wyoming; by the occurrence of high-gravity Cretaceous oil in areas of relatively low carbon ratios near the Black Hills; by the occurrence of very high-gravity oil in several fields in northwestern New Mexico near which Cretaceous coals have carbon ratios whose average is about 55; and by the occurrence of large quantities of gas in the Cedar Creek anticline in eastern Montana, where carbon ratios of the little disturbed Tertiary black lignites have an average of about 52. In fact, instead of finding gas fields segregated in a zone characterized by carbon ratios higher than those in the oil belts, as is generally true in the Appalachian and Mid-Continent regions, we find that in the Rocky Mountain region gas occurs in separate fields contiguous or non-contiguous to oil-bearing structures, in

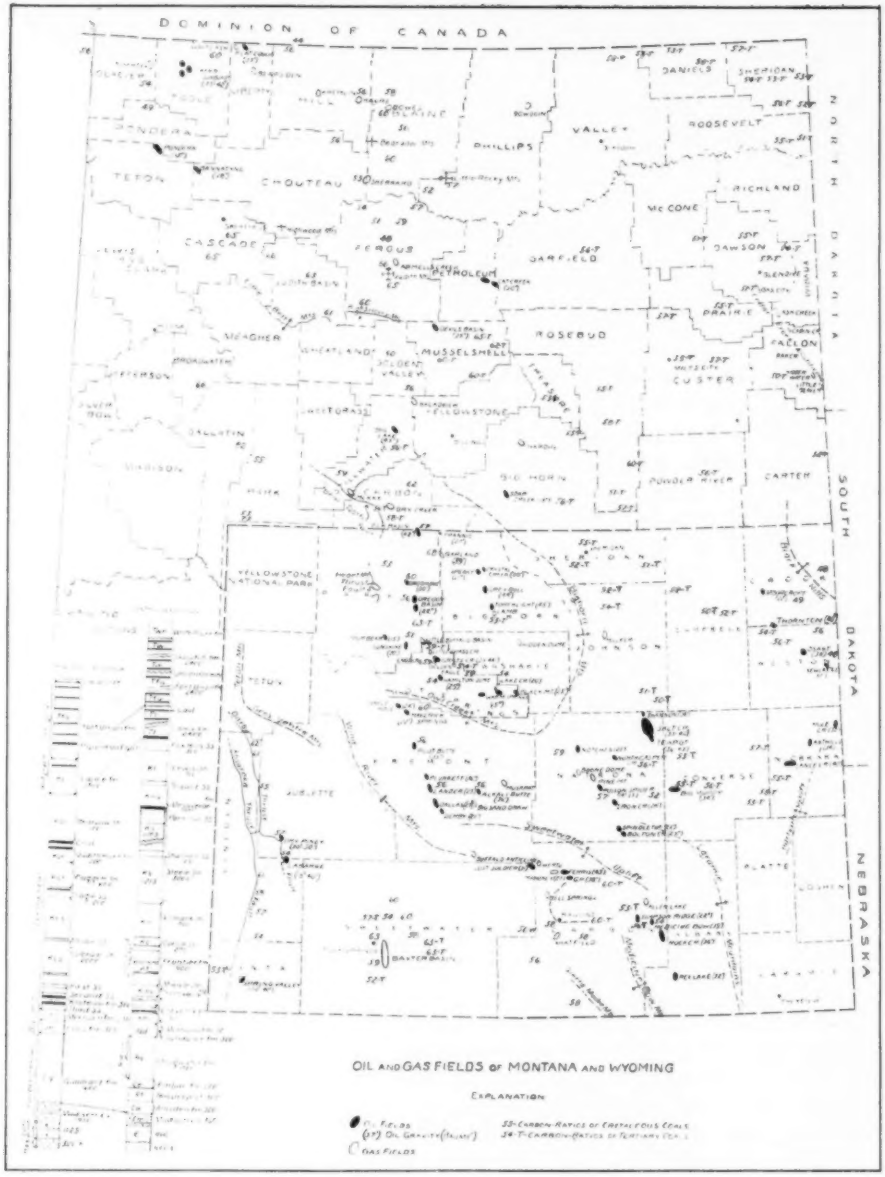
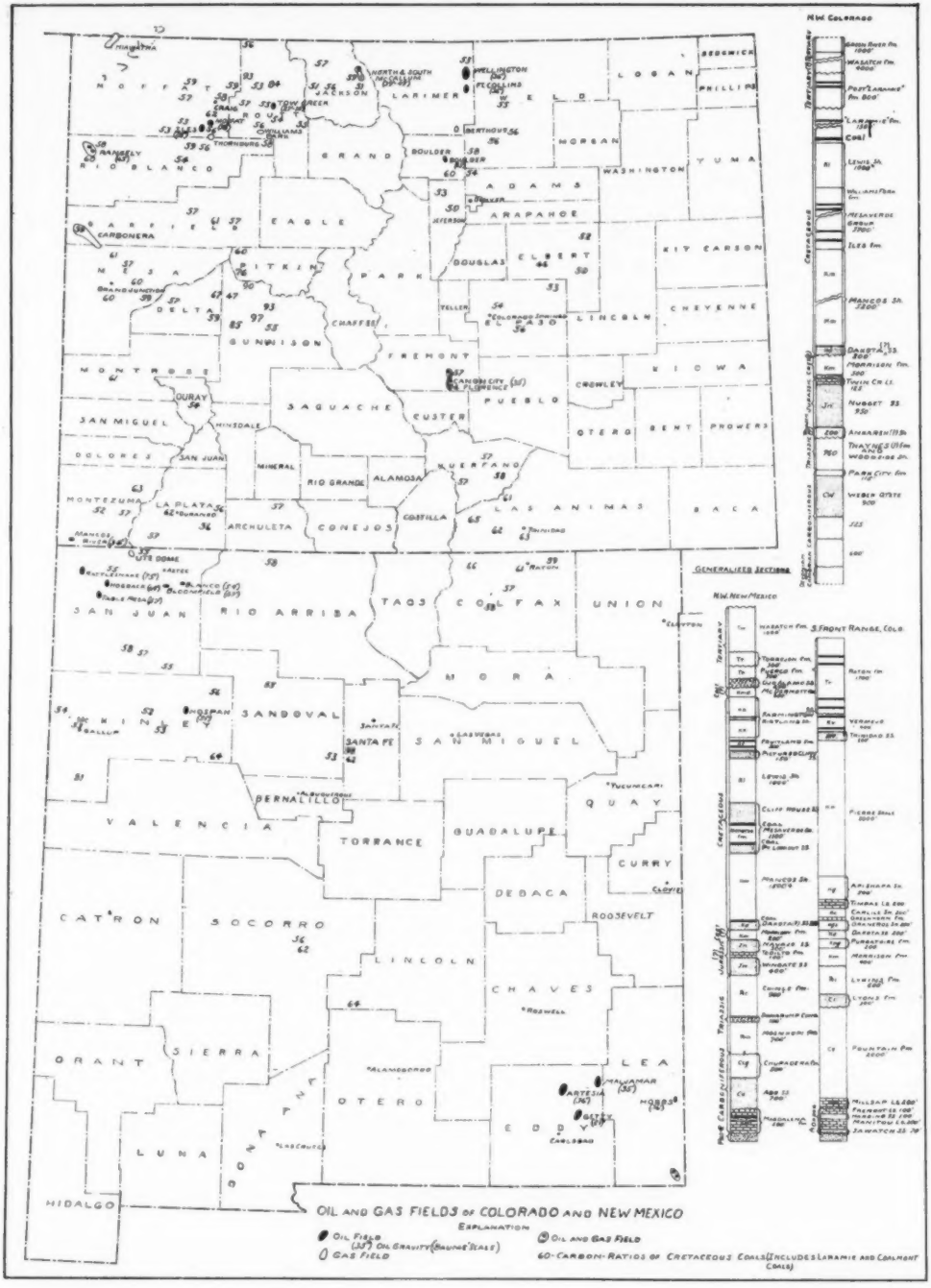

DOMINION OF CANADA
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
DANIELS
SHERIDAN
ROOSEVELT
VALLEY
PHILLIPS
RICHLAND
McCONE
DAWSON
GARFIELD
PETROLEUM
PRAIRIE
FALLON
CARTER
POWDER RIVER
CUSTER
ROSEBUD
MUSSELSHELL
GOLDEN VALLEY
WHEATLAND
MEAGHER
CHOUTEAU
TETON
SANDERS
CASCADE
FERGUS
JUDITH BASIN
PARK
YELLOWSTONE NATIONAL PARK
BIG HORN
YELLOWSTONE
STILLWATER
SWEET GRASS
CARBON
BEAVERHEAD
MADISON
GALLATIN
JEFFERSON
LEWIS & CLARK
BROADWATER
SILVER BOW
DEER LODGE
GRANITE
POWELL
LAKE
FLATHEAD
LINCOLN
SANDERS
MINERAL
MISSOULA
RAVALLI
BEAVERHEAD
DEER LODGE
SILVER BOW
BROADWATER
GALLATIN
MADISON
JEFFERSON
LEWIS & CLARK
TETON
CHOUTEAU
CASCADE
FERGUS
JUDITH BASIN
MEAGHER
WHEATLAND
GOLDEN VALLEY
MUSSELSHELL
PARK
STILLWATER
SWEET GRASS
CARBON
YELLOWSTONE
BIG HORN
POWDER RIVER
CARTER
FALLON
PRAIRIE
DAWSON
RICHLAND
McCONE
GARFIELD
PETROLEUM
ROOSEVELT
VALLEY
PHILLIPS
DANIELS
SHERIDAN
THORNTON
PLATTE
GOSHEN
LARAMIE
ALBANY
CARBON
SWEETWATER
UINTA
LINCOLN
SUBLETTE
TETON
OIL AND GAS FIELDS OF MONTANA AND WYOMING
EXPLANATION
OIL FIELDS
GAS FIELDS

FIG. 1


OIL AND GAS FIELDS OF COLORADO AND NEW MEXICO
EXPLANATION
OIL FIELD
(35°) OIL GRAVITY (BAUME' SCALE)
GAS FIELD
OIL AND GAS FIELD
60- CARBON-RATIOS OF CRETACEOUS COALS (INCLUDES LARAMIE AND COALMONT COALS)
GENERALIZED SECTIONS
NW. COLORADO
NW. NEW MEXICO
S. FRONT RANGE, COLO.
MOFFAT
RIO BLANCO
GARFIELD
EAGLE
GRAND
LARIMER
WELD
LOGAN
PHILLIPS
SEDGWICK
MORGAN
WASHINGTON
YUMA
ADAMS
ARAPAHOE
JEFFERSON
BOULDER
DOUGLAS
ELBERT
KIT CARSON
CHEYENNE
LINCOLN
EL PASO
TELLER
PARK
PITKIN
GUNNISON
CHAFFEE
FREMONT
MESA
DELTA
MONTROSE
OURAY
SAN MIGUEL
DOLORES
SAN JUAN
MONTEZUMA
LA PLATA
SAGUACHE
CUSTER
PUEBLO
CROWLEY
OTERO
BENT
PROWERS
KIOWA
HINSDALE
MINERAL
RIO GRANDE
ALAMOSA
CONEJOS
COSTILLA
HUERFANO
LAS ANIMAS
BACA
ARCHULETA
RIO ARRIBA
TAOS
COLFAX
UNION
MORA
SANDOVAL
SANTA FE
SAN MIGUEL
VALENCIA
TORRANCE
GUADALUPE
QUAY
CURRY
DEBACA
ROOSEVELT
CATRON
SOCORRO
LINCOLN
CHAVES
GRANT
SIERRA
OTERO
LEA
EDDY
LUNA
HIDALGO
DONA ANA
CARLSBAD
ARTESIA
HOBBS
ROSWELL
ALAMOGORDO
LAS CRUCES
RATON
CLAYTON
TUCUMCARI
CLOVIS
LAS VEGAS
SANTA FE
ESPANOLA
GALLUP
FARMINGTON
AZTEC
BLANCO
BLOOMFIELD
DURANGO
MANCOS
DOVE CREEK
DOLORES
NATURITA
GATEWAY
GRAND JUNCTION
CARBONERA
RANGELY
THORNBURG
CRAIG
TOWN OF MAYBELL
HAYDEN
STEAMBOAT SPRINGS
HAHNS PEAK
WELLINGTON
FT. COLLINS
LOVELAND
BERTHOUD
LONGMONT
BOULDER
GOLDEN
BROOMFIELD
LOUISVILLE
LAFAYETTE
ERIE
NORTH & SOUTH MCCALLUM
TOWN OF GREEN
JAMESTOWN
LYONS
ESTES PARK
GRAND LAKE
GREEN RIVER FM. 1000'
WASATCH FM. 4000'
POST "LARAMIE" FM. 800'
"LARAMIE" FM. 750'
COAL
LEWIS SH. 1500'
WILLIAMS FORK FM.
MESAVERDE GROUP 3700'
ILES FM.
MANCOS SH. 7250'
DAKOTA SS. 200'
MORRISON FM. 300'
TWIN CR. LS. 15'
NUGGET SS. 350'
ANNAREE (?) SH.
THAYNES LS. (?) FM.
WOODSIDE SH.
PARK CITY FM. 150'
WEBER QTZITE 900'
JOINT CREEK CARBONIFEROUS
TRIASSIC
JURASSIC
CRETACEOUS
TERTIARY
TORRIFERO FM. 1000'
TERTIARY
TERTIARY
TERTIARY

sands lying both above and below oil-bearing sands, and in areas of both high and low carbon ratios (Plate 12 and Figs. 1 and 2). Another anomalous relation in this region is the occurrence of lower structures, totally or in part gas-bearing, which lie contiguous to higher structures containing oil in the same sand. This is illustrated by Salt Creek (oil) and Teapot (gas and oil) domes, Lost Soldier (oil) and Wertz (gas) domes, Grass Creek (oil and gas) and Little Buffalo Basin (gas) and Enos Creek (gas) fields. According to Irwin,[1] the gas structures here listed are from 200 to 1,900 feet lower structurally than the contiguous oil fields. He also says,[2] "the evidence now available is quite insufficient to account fully for gas only in one closure, and oil only in another immediately adjacent, where the structural relationships, productive horizons, and age of folding are exactly the same."

Owing to the fact that very little deep drilling for coal has been carried out in the Rocky Mountain region, data on the carbon ratios of the coals below ordinary mining depths are so meager that no widespread application of Hilt's law, calling for increase in degree of carbonization with stratigraphic depth, is possible at present. According to Wilson,[3] the so-called Dakota coal found at a depth of 2,505 feet in the Gypsy Oil Company's Maire No. 1 well on Grand Junction dome, Colorado, had a carbon ratio of 63.6 and that from the Midwest Refining Company's Hayden No. 1 well, lying a short distance northwest, had a carbon ratio of 62.6 at a depth of 3,182 feet. Since the carbon ratios of the Mesaverde coals exposed in the bluffs near by, and lying about 4,100 feet stratigraphically above the Dakota coal, range from 57 to 61, it is evident that at this locality the fixed-carbon percentage increase with depth is much less than the average increase of .69 per 100 feet in the Appalachian region as described by Reeves.[4] The carbon ratio of the coal found at a depth of 1,337 feet in a well near Gallup, New Mexico, was reported to be 55.4, whereas the average of the coal exposed near by was 53.

The difficulty in applying the carbon-ratio theory to the Rocky Mountain fields probably seems greater than it really is, inasmuch as it

[1] J. S. Irwin, "Faulting in the Rocky Mountain Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), p. 128.

[2] *Op cit.*, p. 129.

[3] J. H. Wilson, "Lithologic Character of Shale as an Index of Metamorphism," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), p. 629.

[4] Frank Reeves, "The Carbon-Ratio Theory in the Light of Hilt's Law," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12 (1928), p. 801.

arises chiefly from the erroneous use of coal analyses and to a lesser degree from failure to recognize that most of the low-rank coals mined in the West lie at shallow depths and have probably suffered incipient weathering. The appearance of abnormally high carbon ratios for Rocky Mountain low-rank coals results from the failure to recognize moisture as an essential constituent of the "volatile matter" of coal.[1] Were the analyses used on an as-received ash-free basis, the lignites and sub-bituminous coals would indicate the degree of metamorphism very closely.

Moreover, the facts that where the Lower Cretaceous bituminous coal of the Black Hills region, Wyoming, has a thickness of more than two feet it is usually divisible into benches of different kinds, including bituminous, cannel, splint, and "pine needle" coal; that there are notable variations in the percentage of fixed carbon between benches in the same Tertiary lignite bed at Glendive, Montana, owing to canneloid streaks in the bed; and that in any high-rank eastern coal the fixed-carbon content varies greatly in the same bed between mineral charcoal, bright coal, and dull coal, suggest that the average value for the percentage of fixed carbon reported in any analyses of coal is more or less accidental. Furthermore, the vegetable matter which formed the younger western coals was somewhat different in average composition from that which formed the eastern Carboniferous coals and probably responded very differently to metamorphism.

CONCLUSIONS

A consideration of the data herein set forth prompts the conclusion that unless moisture be considered as part of the "volatile matter" of coal, the carbon ratios for western coals below high bituminous rank are probably much less significant as to the intensity of metamorphism than are the general properties of the coal, particularly the tendency to slack. Carbon ratios as ordinarily calculated do not show satisfactorily the rank of low-rank coals, and furthermore the carbon ratios of low-rank coals, if weathered, are a very doubtful measure of the dynamic metamorphism the coals and enclosing strata have undergone. Consequently many analyses of Rocky Mountain coals can not be accurately correlated with metamorphic effect and with oil and gas occurrence—although the carbon ratios of the much restricted semi-bituminous and higher-rank coals of the region probably indicate much the same degree of metamorphic intensity as do those of the eastern Paleozoic coals.

[1] W. T. Thom, Jr., "Moisture as a Component of the Volatile Matter of Coal," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 71 (1925), pp. 282-88.

TEMPERATURE GRADIENT IN PECHELBRONN OIL-BEARING REGION, LOWER ALSACE: ITS DETERMINATION AND RELATION TO OIL RESERVES[1]

I. O. HAAS[2] and C. R. HOFFMANN[3]
Merkwiller-Pechelbronn, Alsace, France

ABSTRACT

Numerous temperature measurements have been made during the last ten years in the Pechelbronn oil-bearing region, to aid in the search for petroleum deposits.

However, the results of the study of approximately 500 measurements clearly show that the isogeotherms are influenced primarily by the tectonic structure of the Rhine Valley graben. They show a nearly regular rise from the edges to the central part of the graben; also not uncommonly they approach one another. Such increase of temperature is especially marked in the fault zones.

Seemingly, the isotherms are not influenced by larger or smaller oil accumulations; therefore, the presence of oil can not be looked upon as the cause of the relatively elevated temperature.

It is perhaps possible to explain the rise of temperature toward the central part of the graben by a gradual change in the nature of the deposits. Coarse-grained sandy beds of the graben edges are gradually replaced toward the center by increasingly finer sands, and finally by finely laminated marls. It is possible that these finest deposits act as a sort of protective cover against the loss of heat. This suggestion would also explain the increase of temperature and the accumulation of heat along the faults, as it is possible to suppose a stronger increase of temperature in the direction of the dislocation in the strata. This suggestion is strengthened by the fact that the especially high horsts are characterized by temperature maxima on the isothermal map.

INTRODUCTION

Several works on temperature measurements in oil wells and on temperature gradients calculated on the basis of these measurements have been published during the last few years, but, although this method of research has attracted little interest in the majority of oil-bearing regions, some authors (26, 27)[4] have perhaps overestimated the value of such measurements for the discovery of petroleum deposits. The writers thought, therefore, that it would be useful to summarize their long experience in this subject and to consider whether it is possible to as-

[1]Manuscript received by the editor, March 30, 1929.

[2]Assistant chief geologist, Pechelbronn Mining Company.

[3]Chief geologist, Pechelbronn Mining Company.

[4]Numbers refer to titles in Bibliography.

certain the existence of petroleum deposits on the basis of a smaller or a larger temperature gradient. They are very glad to thank Mr. Pelissier, director general of Pechelbronn, for permission to publish the results of the experiments. Moreover, they are much indebted to W. P. Haynes, of Paris, for his valuable assistance and particularly for the translation of this article.

The idea of measuring the temperature in oil wells is not an old one. Systematic measurements were only started at the end of the last century. As to the Pechelbronn region, as far as the writers know, the first measurements were started in 1895. However, until 1919, they were taken very irregularly. From this time on, more interest was shown in the matter and a detailed study of all the possible sources of error of the instruments or of the measurement methods was begun. But only after a considerable improvement of the method was it possible to obtain such results as permitted starting a systematic study of the temperature gradient in the Pechelbronn oil field. A tight net of almost 500 measurements permits us, at present, to clear up the relations between the temperature gradient and the oil accumulations. In order to give the reader the possibility of judging the value of the measurements and the elimination of the sources of errors, the writers give first a summarized statement of the errors of the thermometers and of the measurement methods, although some of these points have already been discussed by others, particularly by Königsberger and Muhlberg (10, 11).

DESCRIPTION AND DISCUSSION OF THERMOMETERS USED

The first temperature measurements in oil wells were taken by means of maximum thermometers, (type "Überfallthermomether"), with which good results can still be obtained.

As these instruments are difficult to manipulate and can not be given to workers who are not specially trained, they were long ago replaced in Pechelbronn by ordinary maximum thermometers which, during the course of time, have been altered and improved. Electrical temperature measurements were not undertaken on account of the high cost of this method. The writers do not know the kind of thermometers first used in Pechelbronn, but they probably were of the Überfall thermometer type. At any rate, L. van Werveke, formerly director of the Geological Department of Alsace-Lorraine, was the first to order new instruments, on the basis of indications supplied by Professor Königsberger, Freiburg i–Baden. The fundamental idea of his device is as follows: a maximum thermometer (fever medical thermometer type), with divisions running from 0 to 50° C., and about 30 cm. long, is placed in a hermetically closed

iron pipe. The action of exterior pressure was avoided by protecting the enclosing cap with a lead seal. Several of such iron pipes were put together into a small bailer which was let into the well by means of a line or on rods. The well could be either dry or filled with water. In order to prevent any exchange of temperature, a wooden disc was placed above the box. Six hours is considered to be the minimum time necessary for a measurement.

The first change the writers had to make was to increase the number of degrees (first up to 60° C. and later up to 100° C.). Also, the length of the thermometer was increased from 30 to 35 cm. The iron pipes were later replaced by brass pipes with a double lead seal cover.

In spite of this, the unexpected discovery was made that the protection against exterior pressure was not always sufficient. The thermometer showed too high temperatures. This observation had also been made by Salomon (28).

In some cases, the lead seal was pressed far into the iron or the brass tube, and occasionally, the thermometer itself was crushed. Königsberger tried to improve the situation by constructing a complicated device (10) which, as a matter of fact, permitted him to overcome the pressure action of the water column in the well on the thermometer. But as this device, being very difficult to manipulate, could not be given to ordinary drillers, it was necessary to find a thermometer which would make the use of any supplementary device unnecessary.

The solution of this problem was reached in 1922, when the metal protection tube was replaced by a hermetically sealed glass tube. The thermometer is fixed in the interior of this glass tube by means of cork washers. The glass tube is made in such a way that it can resist a pressure as great as 100 atmospheres.

A series of experiments has proved that, with this new device, the exterior pressure no longer influences the thermometer. The temperature was raised to 56°, and the pressure to 30 atmospheres; in spite of this, no difference could be observed in comparison with a control thermometer. On the contrary, a comparison with an old thermometer in a brass pipe showed a difference of 3°, the temperature being 50°. This difference becomes certainly larger with the increase of the temperature and of the pressure (compare 28). A slight disadvantage of these thermometers is that, whereas with unprotected instruments the reaction period is only 2 minutes, the protected instrument requires 15 minutes. As, however, the time during which the measurements are made is always much longer than 15 minutes, this has no bearing on the result.

The thermometers here described are about 40 cm. long and register as high as 100° C. Half-degrees can be easily read and quarters estimated. As will be seen later, greater precision is not required for the needs of these experiments.

A long time after these experiments, the writers learned of the work of Darton (20), who had constructed a similar instrument in 1920. Although there are some differences in structure between his device and that of the writers, the elimination of the pressure is reached in Darton's instrument just as in this one, by inserting the thermometer in a hermetically sealed glass tube.

POSSIBLE SOURCES OF ERROR IN TEMPERATURE MEASUREMENTS

Königsberger and Muhlberg have reported on the taking of temperature measurements, and they indicate a series of sources of possible errors (10, 11, 29). However, in the following pages, the writers will summarize the points which attracted their special attention and which partly depend upon the drilling system, and partly upon the status of the well during the measurements. These points are here given.

1. The influence of the pressure of the water column in the well on the thermometer.
2. Rise or fall of the temperature of the well, owing to the flushing of the well with cleaning liquids.
3. Loss of heat owing to air or water circulation in the well during the measurements.
4. Decrease of temperature owing to the radiation of heat through casing, rods, and cables.
5. Heating of the bottom of the well by the action of the drilling tools.
6. Too short time of the measurement and poor contact of the thermometer with the well sides.
7. Inefficient operation of the instruments.

In connection with the researches of the writers, these points can be explained as follows.

1. The influence of the pressure on the thermometer is eliminated by the glass tube already described.
2. The influence of liquids flushed into the well for cleaning out must not be underestimated. As, however, in the majority of cases, the temperature of the well is decreased by the flushing-in of the cleaning liquid, a sufficiently long time of measurement is effective for avoiding an eventual error. Nevertheless, it sometimes happens, especially during

the summer, that the temperature of the liquid is higher than the expected temperature of the well. When it is, the well must be bailed dry, and the measurement can be made only after a certain time has elapsed.

3. In order to avoid a loss of heat through water or air circulation during the measurement, it is sufficient to fix above the measuring instrument several flexible rubber washers, of about the same diameter as the well. These rubber washers are better than wooden or metal washers, as they offer less resistance to the upward and downward movement of the instrument in the well.

4. It is evident that the casing, as well as rods and cables, can influence to a certain degree the temperature of the well, as they are good heat conductors. Therefore, it is not possible to make any measurement inside of the casing, or in its immediate vicinity, even if the casing is standing on the bottom of the hole. However, the writers estimate that a distance of 5 meters from the casing is sufficient, provided that not only the thermometer itself, but the rubber washers are also outside of the casing. For the same reason, the writers avoid any measurements with thermometers fixed to rods, and allow in the well only the line to which the thermometers are attached. The ideal would, of course, be to use a thin hemp rope; however, in practice, this can very seldom be done. It was formerly recommended to make simultaneous temperature measurements at various depths in the same well, but recently warnings against this proceeding have been issued (28, 29).

The heating of the bottom of the well by drilling tools, as has been proved by experiments and calculations, can scarcely be taken into consideration when the well is drilled by means of percussion or rotary system, with injection of mud fluid. On the contrary, with the Pennsylvanian and Canadian system, when the hole remains dry, it must be thoroughly cleaned and washed several times with cold water. Moreover, the writers always try to make two measurements within a period of 24-36 hours, during which drilling is suspended, for instance, from Saturday night to Sunday morning, and then from Sunday morning to Monday morning.

6. The writers have tried to make measurements during a shorter time. It might be stated that, usually, 1½ hours did not prove sufficient to obtain the maximum temperature at the bottom of the hole. Seven to eight hours could be indicated as a minimum period for a measurement of a well with mud injection. In the case of a dry drilling system, it is always better to repeat the measurement immediately, as already mentioned.

The influence of the water column being eliminated, it is not important whether the measurement is made in a well filled with water, or in an empty hole, especially as there is always need, in order to obtain a better exchange of temperatures, that even in an empty hole, the thermometer should be covered by a column of liquid at least 5 meters high.

7. A continuous control of the thermometers used is positively indispensable. For this, all the thermometers are compared once a month with a control thermometer, and a correction table is then prepared, by means of which the temperatures obtained during the depth measurements are corrected. In principle, the writers are content with a precision of $\frac{1}{4}°$-$\frac{1}{3}°$ C., which they think is entirely sufficient, as in the calculation of the temperature gradient it is necessary to operate with the depth measurement which can also show errors as large as one or two meters.

CARRYING OUT TEMPERATURE MEASUREMENTS

The majority of the geothermic measurements, accounts of which have been published, have the disadvantage that they have been carried out in a relatively small number of wells, which occasionally could lead to hasty conclusions as to the underground geothermic conditions.

Therefore, it seemed positively necessary to carry out temperature measurements as often as possible in the fields. But this could be done only when such a measurement would involve slight cost, that is, when it would not interrupt drilling, or cause much extra work. Moreover, the whole proceeding must be simple, so that the measurement could be made by an ordinary driller. This may be accomplished in the following way.

The driller puts two or three cooled thermometers, properly shaken down, into a perforated iron box, which itself is then put down into a small bailer provided with rubber washers and let into the well on a line. This is generally done at the end of the last Saturday tour, so that the thermometer can remain at the bottom of the well until Monday morning (a minium of 24 hours). The thermometers are then pulled upward as gently as possible, the box is taken out and put into cold water.

The thermometers can be read as soon as they are quite cooled. All the data necessary for the measurement are written on a special sheet, which is then forwarded to the geological department. (See Table I.) The geologist corrects the measurements on the basis of the previously mentioned correction table and adds all the remarks which could be of value for the consideration of the measurement. The temperature gradient is then calculated.

TABLE I

SAMPLE FORM FOR TEMPERATURE RECORD

Pechelbronn S. A. E. M.

WELL NO.....

Temperature Measurement

1. Field.....
2. Depth of well.....meters
3. Casing-shoe depth.....meters
4. Height of the liquid in the well.....meters

Thermometers

5. Depth of measurement.....meters
6. Inserted at.....o'clock, on the.....192
7. Withdrawn at.....o'clock, on the.....192
8. Duration of measurement.....hours
9. Thermometers.....No.....No.....No.....

Temperatures { Before measurement..... / After measurement.....

Field Superintendent

10. Temperature corrected.....°.....°.....°.....
11. Temperature average.....°
12. Temperature gradient.....meters.....meters
13. Geologic formation.....

REMARKS:

Geological Department

CALCULATION OF TEMPERATURE GRADIENT

For the calculation of the temperature gradient, the writers use the formula of Professor Königsberger (11):

I $$G = \frac{L}{T - T'}$$

where: G = temperature gradient
L = depth of measurement below ground
T = corrected average temperature shown by the thermometers
T' = average temperature at the casing head

II $$T' = t' + t''$$

where: t' = average temperature of the air
t'' = correction for the elevation of the well above sea-level which, in the Pechelbronn field, is equal to 0.9° C.

The average temperature is 9°, and T' is, therefore, equal to 9.9° C. For the calculations it can easily be admitted that $T' = 10°$ C.

Therefore, formula I can be read as follows:

III $$G = \frac{L}{T - 10}$$

With this formula is obtained the geothermic gradient between the measurement point and the ground level.

Moreover, in all cases where measurements at varying depths are made, it is much more important to calculate the variations of the temperature gradient from one depth to another. This new value is called intermediate gradient, or Gi.

IV $$Gi = \frac{Ln - L(n-1)}{Tn - T(n-1)}$$ where: Gi = intermediate geothermic gradient

Ln = depth in meters of the nth measurement point

$L(n-1)$ = depth in meters of the preceding measurement point

Tn = temperature of the nth measurement point

$T(n-1)$ = temperature of the preceding measurement point

CRITICISM OF RESULTS OBTAINED

It is evident that every result of the measurements must be submitted to a detailed analysis, which should take into consideration all the patriculars concerning the carrying out of the measurements and the status of the wells.

In addition to the purely technical sources of error connected with drilling which have already been referred to, there is a series of cases which must be considered, when an application of the results is made. The writers propose to call them physical error possibilities and will differentiate the following two cases.

1. A flow of water coming upward from the bottom of the well, or downward behind the casing may increase or decrease the temperature abnormally.

2. Measurements which are made in a petroleum- or gas-bearing bed generally show an abnormally low temperature which is provoked by the liberation of the gas.

Other causes which may bring about a local rise of temperature are also possible and remain to be determined in the course of future experiments.

It is always better to discard all doubtful measurements, and to repeat them, if possible, under more favorable conditions. At any rate —although this may seem to be illogical—measurements which are made in the presence of an oil flow *can not be used at all* for the determination of the underground temperature and particularly of the temperature of the oil reservoir.

APPLICATION OF RESULTS OBTAINED

In order to make full use of the results obtained, it was necessary to study all the possible relations between the temperatures measured and the external conditions. It was necessary to consider particularly the following conditions: first, relations between the point of measurement and the temperature; and second,

1. The mountain border
2. Some of the principal strata
3. Tectonic lines, especially faults
4. Facies of the beds
5. Extent of the productive petroleum horizons and of the unproductive bituminous deposits.

The results obtained were plotted on cross sections, and in that way the isotherms from 20° to 60° C. were drawn. Three of the most important cross sections are shown in Figure 1. The writers have tried to give two sorts of presentations on these sections. On profiles 1 and 2, the casing heads of all the wells are supposed to be on one level. If the scale of these sections is considered, the adjustments which are thereby occasioned are almost imperceptible; also this gives a certain advantage for the studying of the isotherms.

On the contrary, on profile 3, the ground relief has been left for comparison. Because of the small differences in elevations, the isotherms are practically the same as on profiles 1 and 2.

The extent of the oil reserves has been determined by numerous wells, which are, however, not shown on the profile, in order not to overcrowd the design. Only those wells are shown on the profile in which temperature measurements were made (mostly 2-7 measurements per

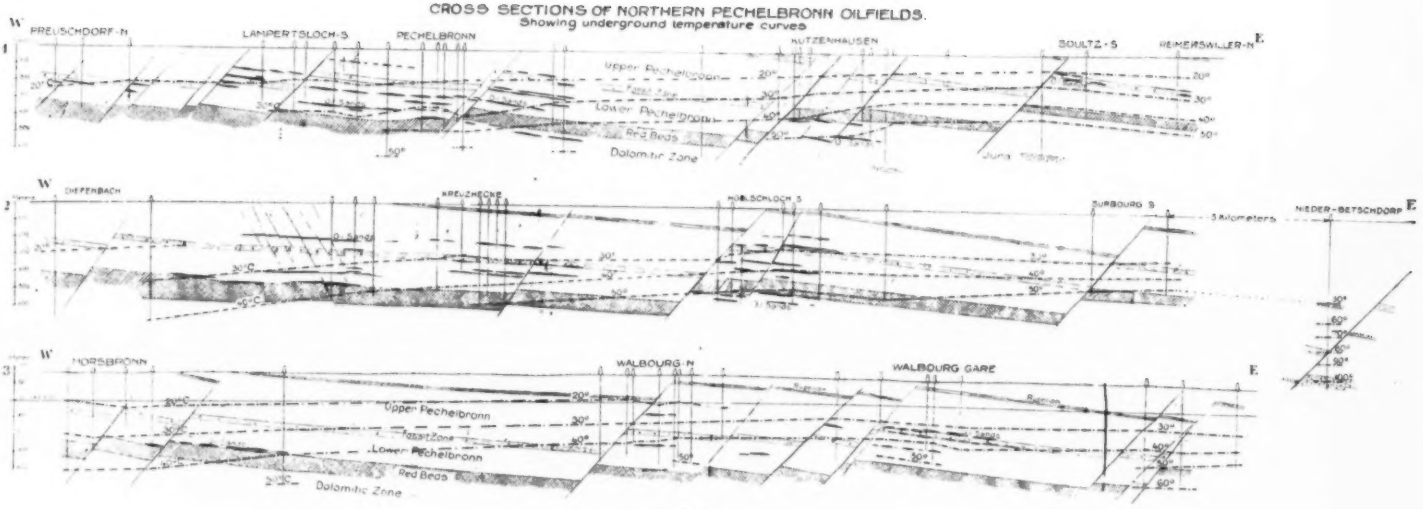

CROSS SECTIONS OF NORTHERN PECHELBRONN OILFIELDS.
Showing underground temperature curves
W
E
1
PREUSCHDORF-N
LAMPERTSLOCH-S
PECHELBRONN
NUTZENHAUSEN
SOULTZ-S
REIMERSWILLER-N
Upper Pechelbronn
Lower Pechelbronn
Red Beds
Dolomitic Zone
2
DIEFENBACH
KREUZMONT
HOH-SCHLOCH-S
SURBOURG-S
5 Kilometers
NIEDER-BETSCHDORF
3
NORSBRONN
WALBOURG-N
WALBOURG GARE
Upper Pechelbronn
Lower Pechelbronn
Red Beds
Dolomitic Zone

FIG. 1

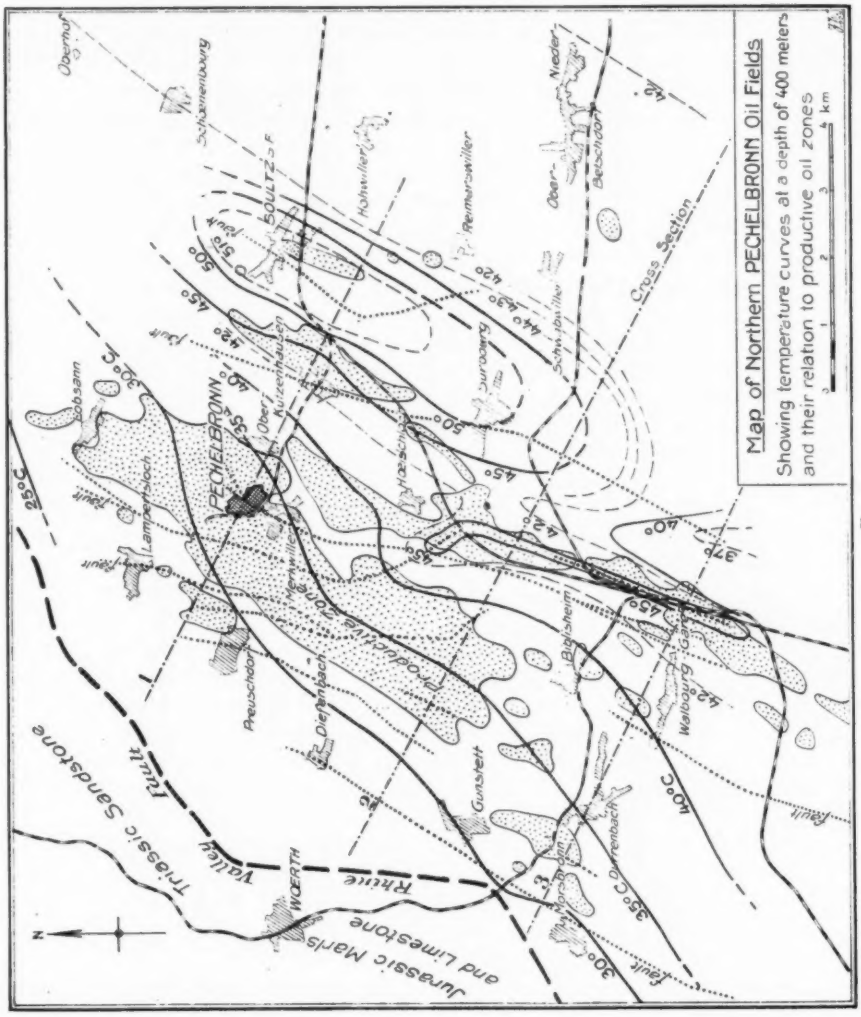

Map of Northern PECHELBRONN Oil Fields
Showing temperature curves at a depth of 400 meters
and their relation to productive oil zones
Cross Section
PECHELBRONN
Jurassic Marls and Limestone
Triassic Sandstone
Rhine Valley
WOERTH
Gunstett
Preuschdorf
Diefenbach
Lampertsloch
Bobsann
Oberhoffen
Hatten
Durrenbach
Walbourg
Bilgisheim
Reimerswiller
Hohwiller
Schaffenburg
Oberhoffen
Soultz s/F
Niederbetschdorf
Oberbetschdorf
Fault
Fault

FIG. 2

well). The small map (Fig. 2), which shows the course of the isotherms at the depth of 400 meters, includes only the northern part of the region where these experiments were made. Moreover, this map shows the productive oil zones, and some of the most important faults.

The study of this material leads to the following conclusions.

The isotherms show the same characterisitcs in each of the three profiles.

Near the principal zone of dislocation in the west, the isotherms lie twice as deep as in the east. They rise fairly regularly from west to east, and they approach one another. The maximum elevations of the isotherms are reached on the three profiles respectively at Soultz, Surburg, and Walburg-station. Thence, the isotherms decline very slightly toward the east, or else are almost horizontal, which is especially well marked on profile 2, where a well, located at a distance of 5 kilometers, shows only a slightly higher temperature gradient. The writers found there, at a depth of 700 meters, a temperature of 70° C., whereas at the western edge of the same profile the thermometer showed 40° C.

Small irregularities of the isotherms on the profiles must be studied in detail.

It appears that, in several profiles, the curves show a strong rise where the faults are located, for example on profile 1, in the region of Lampertsloch, Kutzenhausen, and Soultz; on profile 2, the region of Hoelschloch and Surbourg; and on profile 3, in the region of Walbourg and Walbourg-station.

The irregularities of a curve, such as those shown by the 30° isotherm on profile 1, are perhaps due to the fact that the measurements were made in the presence of a gas or water flow. The writers possess too few measurements, made under such circumstances, to check the correctness of those which they have.

The correlations between oil accumulations and temperatures can also be clearly seen on the profiles.

Although the eastern part of the oil field (Pechelbronn-Kreuzhecke) contains oil deposits, which are as rich as, and even more extended than, the deposits of the eastern part (Kutzenhausen-Surbourg-Walbourg), the temperatures are not at all the same. In the western part, they are only about half as elevated as in the eastern part. In some places, it is observed that, in the oil-bearing zones, the isotherms are inclined to follow the dip of the beds (Lampertsloch-Soultz, Walbourg-station).

The isothermic map (Fig. 2) makes it possible also to observe a series of valuable details.

With the exception of the region of Morsbronn, where the Rhine Valley fault turns sharply (northwest of the map), many isotherms run almost parallel with this fault. This is particularly true with the 25°, 30°, 35° and 40° isotherms. It clearly appears that the exploited oil pools are crossed by the isotherms in all possible directions.

A series of faults, some of which are shown on Figure 2, seem, moreover, to exercise a certain influence on the isotherms. This seems to be particularly true with the 40° curve, between the villages of Pechelbronn and Biblisheim, whereas the other isotherms show only a much flatter indentation in a northwest direction.

The 45° isotherm shows some important peculiarities.

It shows two different maxima zones. The first is located between Hoelschloch and Walbourg-station and is a very narrow zone, extending north-northeast, which, at its northern end, is clearly influenced by faults. Toward the south, this isotherm runs parallel with another fault, which passes through Walbourg-station. This maximum temperature zone coincides partly with the oil-bearing zone which extends along the railway, although the best producing wells are located west of this maximum zone.

The other maximum zone, the center of which is near Soultz, is parallel with a fault which lies west of a rather unimportant oil pool. Although the rich oil zone of Kutzenhausen is close to this second maximum zone, the highest temperature is found near Soultz, that is, at a distance of at least 1½ kilometers east of this place. The correlation between temperature maxima and faults is clearly shown by this example, whereas the correlation between oil accumulations and temperature maxima seems to be very doubtful.

In the following zone, which extends eastward as far as Betschdorf, few measurements are available, so that nothing definite can be said about the details of the course of the isotherms. It is very possible that only a few faults are located between Betschdorf and Soultz and that the isotherms are influenced in a still stronger way by the southeast-dipping beds.

ATTEMPT AT AN EXPLANATION OF TEMPERATURE VARIATIONS

In the search for an explanation of these rather peculiar temperature variations, the hypothesis of a volcanic influence in the subsurface of the Rhine Valley must be eliminated. Although there is plenty of evidence of Tertiary volcanic activity in the Rhine Valley, it is located almost exclusively in the southern part of the graben. But precisely in this region, in the immediate vicinity of these volcanic remnants, numer-

ous measurements were made, especially in the potash borings on both sides of the Rhine. As far as the writers know, the geothermic gradient is almost constant in this region and equals about 20 meters.

On the contrary, in the oil-bearing region, the geothermic gradient varies between 6 and 32 meters and shows a tendency to increase at depth (below the Red marls), which is shown on the profiles by the 40° and 50° curves. This alone completely eliminates the possibility of an abnormal heat flow from depth.

The question now arises whether the oil itself can be considered as the source of heat, explaining the abnormally small temperature gradient. A glance at the map and profiles clearly shows *that there is no regular correlation between the oil pools or productive horizons and the isotherms.*

Mention is made only of the following two examples.

In one of the richest zones of the region, between Lobsann-Pechelbronn and Biblisheim where, in its northern part, there are at least four productive horizons lying one above another, comparatively low temperatures are observed, and the temperature curves do not seem to be influenced at all by the extension of the field. On the contrary, the highest temperatures are observed near Soultz, where only a small and unimportant field is known, and near Surbourg where all the wells drilled were dry.

This fact is in contradiction to the widely spread opinion according to which the small geothermic gradients are due to the creation of heat in the oil field itself, this being a result of polymerization or oxydation, or else of radioactivity.

It would be logical to suppose that the quantity of heat created in such a way would be proportional to the quantity of crude in the ground. The highest temperatures would then be observed in the most productive zones, *which, however, is by no means the fact.*

But the correlation between elevated temperatures and faults has already been mentioned. Similar observations were made by van Orstrand and others in the North American fields. There is, moreover, a correlation between the petrographic character of the sediments and the temperature. In the northern part of the Pechelbronn region, from the mountain edge toward the central part of the graben, a gradual decrease may be observed in the size of the grains. In the western part, conglomerates, sands, and compact marls are prevalent, whereas finely laminated clayey marls are relatively rare. Toward the east, conglomerates and sands are gradually replaced by finely laminated marls

many of which contain coal or bitumen finely distributed. Such schistose or marly deposits, especially if they are coal-bearing or bituminous and show only a very small dip, are much worse heat conductors than compact beds (25, p. 194) which consist primarily of coarse-grained components. The exchange of heat in a vertical direction will, therefore, be much slower in the first class of deposits than in the second, so that here may be observed a sort of protective cover. Therefore, the temperature must be much more elevated in the eastern part of the Pechelbronn field than in the western part.

As, however, because of the faults, the eastern horsts lie higher, and as the heat shows a tendency to extend *along* the beds rather than *perpendicular* to them, *a particularly elevated temperature is observed in the fault zones*. This explanation is confirmed by a fact which can be observed with the help of the map (Fig. 2). The principal Rhine fissure separates the Triassic sandstone from the Tertiary deposits in the northern part of the region. In this region, in addition to the coarse upper Triassic conglomerates, a large quantity of sands and sandstones in the Tertiary deposits is observed, but south of Woerth, the fault separates the marly Jurassic beds from the Tertiary formations, which consist of Jurassic material. In this region, the temperature curves approach, in a striking way, the principal fault (vicinity of Gunstett and Morsbronn).

The abnormal temperatures in the Rhine Valley region can thus be explained by a gradual change of heat conductivity of the Tertiary deposits, the heat concentrating especially in zones of stronger tectonic upheavals. (The fact that graben formations show, in general, rather elevated temperatures can not be discussed here.)

This explanation can also be easily brought into correlation with the fact that, in the immediate vicinity of oil reservoirs, the temperature gradients can be smaller, as was observed in several wells. An oil reservoir acts as a sort of protective cover against the expansion of heat upward. Therefore, an accumulation of heat must take place in the vicinity. The problem of the good or poor conductivity of the rocks for the explanation of the various geothermic gradients has been discussed by Königsberger and Ambronn (25, p. 190), (29).

The importance of heat accumulation in the vicinity of petroleum reservoirs is, however, so small in comparison with tectonic and sedimentation effects that a small temperature gradient can in no way be interpreted as an indication of the presence of productive oil sand underground.

It is certain that similar temperature conditions prevail also in other oil fields. The data for a definite judgment are, however, insufficient in most places because of the missing measurements. Moreover, there are no definite proofs that oil is to be considered as a direct or even indirect source of heat. This suggestion is based only on theories attempting to explain this possibility. Therefore, the writers, concurring with Ambronn (31), can not admit the views of several other authors (Warner, 23, 24), according to which favorable locations for the drilling of oil wells could be found by means of temperature measurements in shallow bore holes.

The foregoing considerations, in the opinion of the writers, prove that, at least in the Pechelbronn field, this is impossible. Systematic measurements which are at present carried out in the fields of the United States will add some more valuable data and lead to interesting conclusions on this very important problem of underground temperatures for the solution of which these observations are only a small contribution.

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SUBSURFACE STRUCTURE OF SOME UNSYMMETRICAL ANTICLINES IN THE ROCKY MOUNTAINS[1]

JOHN G. BARTRAM and J. E. HUPP[2]
Denver, Colorado

ABSTRACT

In the Rocky Mountain states the location of deep test wells on unsymmetrical anticlines has been a hazardous undertaking, and wells in surprisingly large numbers have been poorly located. This paper is a study by means of cross sections of many such folds. Past mistakes are analysed and the suggestion made that more attention be paid to regional conditions and the character of the entire anticline and less to the local dips at the surface axis. It will be necessary to survey the course of deep wells and determine the amount and direction of their deviation from vertical, in order thoroughly to understand subsurface structure on unsymmetrical anticlines.

GENERAL STATEMENT

The search for new oil fields in the Rocky Mountain states has led from the exploration of gently folded anticlines with the oil horizon at shallow depths to that of steep and sharply folded anticlines in which the objectives may be very deep. Most folds of the latter type are unsymmetrical, and the dip of the steep side may be 20°-70° steeper than of the gentle side. Some are even overturned and the two limbs are parallel. On such unsymmetrical folds the axial plane is not vertical, but is inclined toward the low-dip side, as Figure 1 shows in an anticline in Paleozoic limestones near Banff, Alberta, Canada. The axial plane of many folds is not a true plane, but is a curved and warped surface. It is a theoretical problem to locate a test well to reach the axis in a particular stratum and to predict the depth to that stratum. Many wells on unsymmetrical anticlines have found their objectives much lower than expected, and a surprisingly large number have failed entirely to reach them. This has greatly increased the hazard and expense of drilling wildcat wells in the Rocky Mountains.

METHOD OF STUDY

In a study of this problem, the writers have drawn cross sections through most of the unsymmetrical anticlines on which wells have been

[1]Read before the association at the San Francisco meeting, March 22, 1928. Manuscript received by the editor, April 5, 1929. Published by permission of the Midwest Refining Company.

[2]Geologists, the Midwest Refining Company.

FIG. 1.—Unsymmetrical anticline in Paleozoic limestone near Banff, Alberta, Canada, showing inclination of the axial plane.

drilled. The available surface and subsurface information was drawn to scale on these, and the unknown structure sketched to agree best with the known facts. The work has not developed any new theories or methods for predicting subsurface conditions but does reveal the nature of the mistakes made in the past, and suggests certain general principles that can be followed to advantage. Some of the cross sections are published here to make the information available for discussion and study as more wells are drilled.

REGIONAL STRUCTURE

The anticlines described are almost all in Wyoming, in the central part of the Rocky Mountain province. The regional structure is the result of intense folding and faulting that occurred in late Cretaceous and early Eocene time. Prior to this folding, many thousand feet of sediments had been deposited in the area with remarkable regularity and angular conformity. The greatest deposition was in eastern Utah, southeastern Idaho, and western Wyoming, where the Triassic, Jurassic, and Cretaceous formations are much thicker than farther east.

The folding and faulting were caused by a tremednous overthrusting movement from the west toward the east, and it was most intense in the area of maximum deposition already mentioned. In eastern Utah, Idaho, and western Wyoming, the sedimentary beds were pushed into long, narrow, parallel waves of anticlines and synclines, some of which broke to form thrust faults, as the uppermost rocks were pushed still farther east. Figure 3 is a generalized cross section from southeastern Idaho east across Wyoming, and it shows the eastern edge of this belt of intense folding and overthrusting. There are several large overthrust faults, and three of them, the Bannock,[1] Absaroka,[2] and Darby,[3] are well known (Fig. 2). Their great size is shown by the facts that the Bannock fault is known to have a horizontal overthrust in Idaho of at least 30 miles, that the Darby fault at one place in Wyoming has a vertical displacement of more than 20,000 feet (lower Paleozoic on top of Upper Cretaceous), and that the Absaroka fault extends north and south in a gentle arc of 150 miles.

[1]R. W. Richards and G. R. Mansfield, "The Bannock Overthrust, a Major Fault in Southeastern Idaho and Northeastern Utah," *Jour. Geol.*, Vol. 20 (1912), pp. 681-707.

[2]A. C. Veatch, "Geography and Geology of a Portion of Southwestern Wyoming," *U. S. Geol. Survey Prof. Paper 56* (1907), pp. 109-10.

[3]A. R. Schultz, "Geology and Geography of a Portion of Lincoln County, Wyoming," *U. S. Geol. Survey Bull. 543* (1914), pp. 84-85.

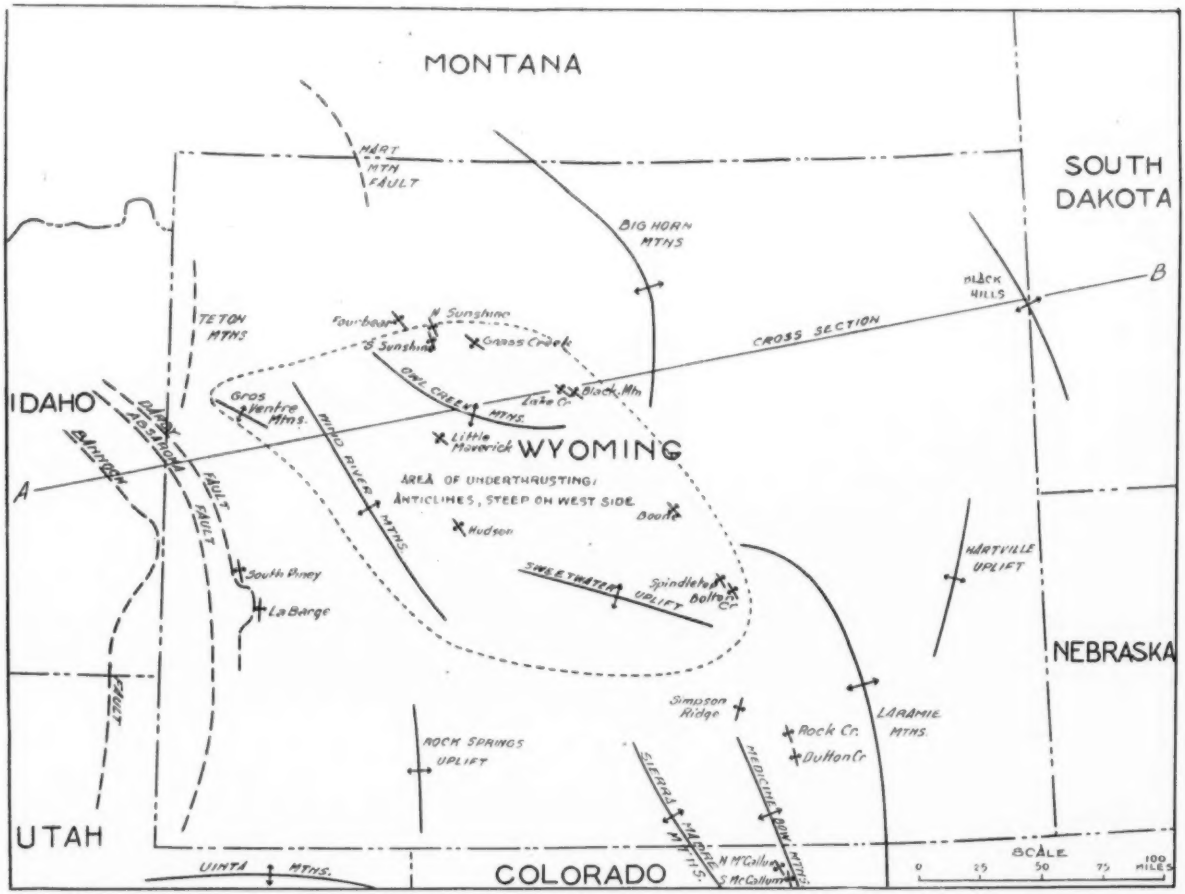


FIG. 2.—Map of Wyoming and parts of adjacent states to show the principal structural features, and the location of the unsymmetrical anticlines that are discussed. Notice the elliptical area of underthrusting in west-central Wyoming.

As this thrust force from the west moved through the fairly competent rocks of Wyoming, it of course met an almost equal resistance. The result was that the rocks were folded into a series of large anticlines (Fig. 3) that are the present mountains, and large synclines that are the basins. Flanking the large folds are the smaller anticlines on which the oil and gas fields occur.

CLASSIFICATION OF ANTICLINES

A study of anticlines in Wyoming shows that they may be divided into two groups, according to whether the steepest side is on the east or west side of the fold, that is, away from or toward the direction from which the thrust came. Such a classification shows there is a large, oval-shaped area in west-central Wyoming where, almost without exception, the anticlines are very steep on the west or southwest side. Outside of this area, both east and west of it, nearly all the unsymmetrical folds are steepest on the east or northeast side. It is not believed that this condition can be explained by thrusting from different directions, or need be. When the thrust force was exerted from the country west of Wyoming toward the east, it was certain to meet different amounts of resistance in different layers of the earth's crust. If in one area there were less resistance to lateral movement in the formations near the surface than in deeper rocks, the upper beds would move toward the east over the lower beds. This would push over the tops of the anticlines, make their east sides very steep, and if continued far enough would overthrust them.

In another area, if there were less resistance in a lower level, the principal movement would occur in lower beds. The west side of the anticlines would be pushed under, steepened, or underthrust. In brief, that is the situation in Wyoming. In some areas all the anticlines are of the overthrust type and in others of the underthrust type. The position of any anticline in one of these areas will tell much about the subsurface structure, and disregard of the regional feature is the cause for most of the poor locations on steep structures. In an area of underthrusting in Wyoming where the steep side is on the west, the axial plane is inclined toward the east, even though the local surface dips near the axis may suggest the opposite. On several anticlines, the local surface structure has been very misleading and has caused expensive failures. When the dip of the axial plane is calculated by merely bisecting the angle between the limbs of the fold, or by rather complex geometrical projections[1], the results are worthless if the observed surface dips do not persist with depth.

[1]D. M. Collingwood, "Graphic Method for Determining the Surface Projection of the Axis and Crest Traces at any Depth of an Asymmetrical Anticline," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5 (1921), pp. 159-62, and 328.

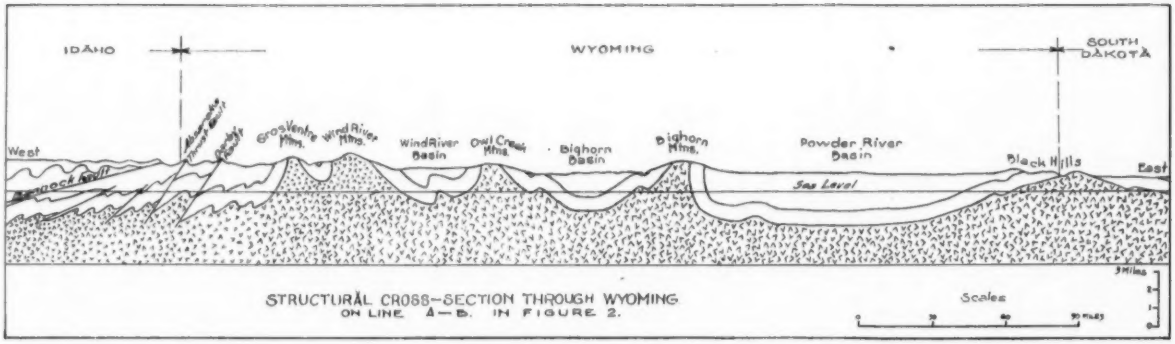


FIG. 3.—Generalized cross section of Wyoming and parts of Idaho and South Dakota, showing overthrust faults on western edge and manner in which some anticlines have tended to overthrust and others to underthrust. Section drawn along line *A-B* in Figure 2.

To determine subsurface conditions on an unsymmetrical anticline, the writers prefer the graphical method of drawing cross sections. With the axis, dips, and limits and thicknesses of formations known on the surface, the cross section can be built up. First the outside edges or limbs of the fold are drawn and the different formations are plotted on the sides with their normal thicknesses. On the crests of the folds, the beds will be thickened, but no conclusive proof is known of very appreciable thinning of formations on the flanks of a fold in Wyoming. With the sides thus drawn, the several beds are projected toward the axis, and the structure is sketched until the most plausible picture is made. This method has been fairly successful, except where concealed faulting has complicated conditions. Another source of error on a few anticlines has been the incompetency of some stratum that crushed and left a thickened zone of disturbed beds.

DESCRIPTION OF CROSS SECTIONS

The cross sections of several anticlines are shown with brief descriptions of their important features.

Rock Creek.—The Rock Creek field[1] (Fig. 4) in southern Wyoming is on one of several closed structures on a long anticline that is east of, and parallel with, the Arlington thrust fault along the east side of the Medicine Bow Mountains. The fault has a vertical displacement of more than 8,000 feet, and the basal granite is thrust over Upper Cretaceous formations. As might be expected from its position, the anticline is of the overthrust type, steep on the east side with dips of 50°-75° and perhaps greater. The dips on the west side are 25°-30°. The fold is fairly broad and the oil sands were only 2,500 feet deep on the crest, so that it was not difficult to locate the pool with the first well. Development has shown that the axial plane is inclined about 16° from vertical and bisects the angle between the two limbs.

South McCallum.—The South McCallum anticline[2] (Fig. 5) is on the west side of the Medicine Bow Mountains, and south of Wyoming, in Colorado. It is also of the overthrust type with a very steep east side. The surface beds are vertical within 800 feet of the axis and beyond that are slightly overturned. The first well was located 1,600 feet west of the surface axis and it is claimed to have found water in the Dakota sand at 3,927 feet. Samples were not saved and some geologists believe the

[1] N. H. Darton and C. E. Siebenthal, "Geology and Mineral Resources of the Laramie Basin, Wyoming," *U. S. Geol. Survey Bull. 364* (1909), pp. 50-51.

[2] A. L. Beekly, "Geology and Coal Resources of North Park, Colorado," *U. S. Geol. Survey Bull. 596* (1915), pp. 90-92.

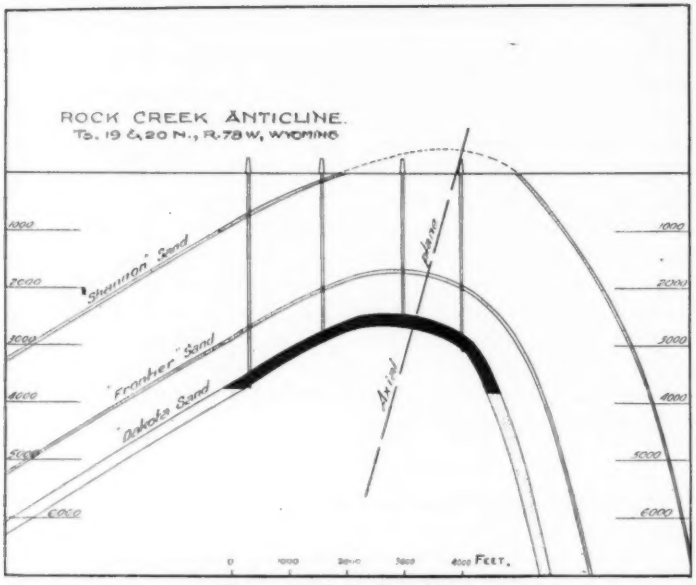


FIG. 4.—Rock Creek anticline.

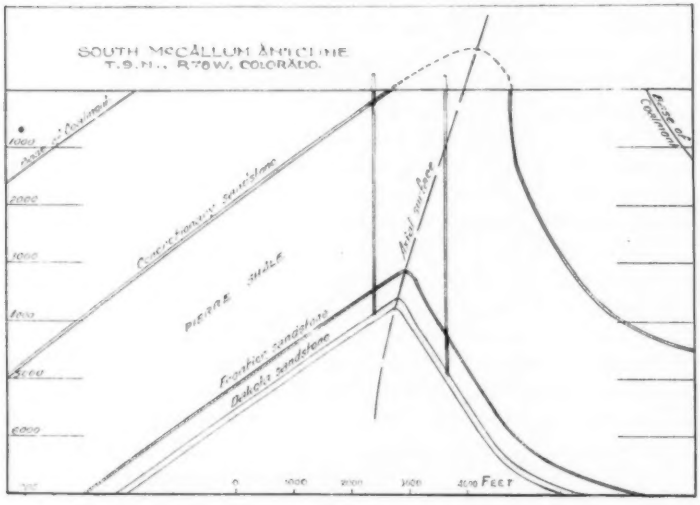


FIG. 5.—South McCallum anticline.

sand was not reached. A second well was drilled within 300 feet of the surface axis and reached the Frontier sand at 4,132 feet and the Dakota sand at 4,875 feet. It is believed that the first well was west of the axis in the Dakota sand and the second was east. The interval between the Frontier and Dakota sands in the second well is abnormally long and is evidence that the well was on the steep side. Since the second well developed a large volume of gas in the Dakota sand, it is probable that the first well did not reach the sand.

Simpson Ridge.—The Simpson Ridge anticline[1] (Fig. 6) is another of the overthrust type in southern Wyoming. It is included to show the disastrous results of a well that was improperly located very close to the axis of a sharp, unsymmetrical fold. On the east side of the anticline, the strata are vertical 2,300 feet from the axis, and on the west flank

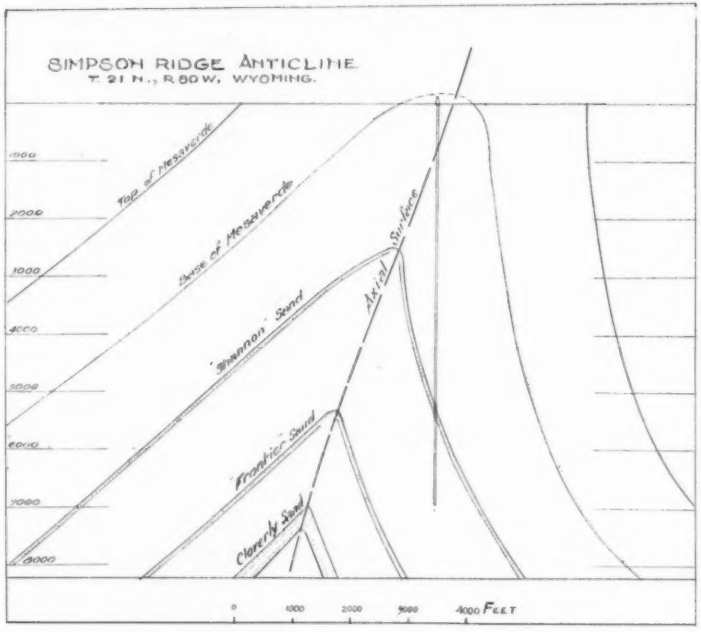


FIG. 6.—Simpson Ridge anticline.

[1]A. C. Veatch, "Coal Fields of East-Central Carbon County, Wyoming," *U. S. Geol. Survey Bull. 316-D* (1906), pp. 250-51.

there are dips as steep as 45°. The deep test well headed for the Dakota sand was located within 200 feet of the surface axis and must have gone onto the steep side at a shallow depth, for it drilled to 6,931 feet without reaching either the Frontier sand or the Dakota sand. If the beds had been horizontal, the well should have reached the Frontier sand at 3,500 feet and the Dakota sand at 4,200 feet. However, the fold is so sharp that the cross section shows the Dakota sand 7,000 feet below the surface at the shallowest point and the axis in the Dakota 2,200 feet west of the surface axis.

La Barge.—The La Barge field[1] (Fig. 7) in western Wyoming is probably not on an unsymmetrical anticline, but on a complex faulted structure of similar character. Some geologists are of the opinion that there is a fairly regular anticline in the Frontier sands beneath the present oil field. The writers' guess as to the subsurface structure is shown in the cross section and does not assume any favorable structure in the Cretaceous rocks beneath the field. It is possible that the subsurface structure is a more complex system of faults and close folding. The La Barge field is located about 2 miles east of the Darby overthrust fault which has pushed early Paleozoic limestones over Upper Cretaceous beds, a vertical displacement of more than 20,000 feet. Parallel with the Darby fault is a smaller thrust fault, now called the La Barge fault, which has thrust Hilliard shale of Upper Cretaceous age over some Tertiary beds. A small anticline was formed in the Tertiary beds in front of the La Barge fault and oil that originated in the underlying, unconformable Hilliard shale has accumulated in this anticline. The structure in the Hilliard shale beneath the field is still unknown, even though two wells in different parts of the pool have drilled below 4,700 feet. Neither of them encountered the Frontier formation, which should have been easily reached, if the folding was gentle. Assuming that the La Barge fault originated from an overturned fold that finally broke, the anticline or faulted anticline in the Frontier sands may be expected west of the field, perhaps somewhat as shown in Figure 7.

Boone.—Boone dome[2] (Fig. 8) in central Wyoming is on the eastern edge of the large area of underthrusting shown in Figure 2. It really should not be called a dome, for it is an elongate, unsymmetrical anticline. The steep side is on the west, since it is an underthrust fold and 4,000 feet

[1]A. R. Schultz, "Geology and Geography of a Portion of Lincoln County, Wyoming," *U. S. Geol. Survey Bull. 543* (1914), pp. 79-80.

[2]C. J. Hares, "Anticlines in Central Wyoming," *U. S. Geol. Survey Bull. 641-I* (1916), p. 270.

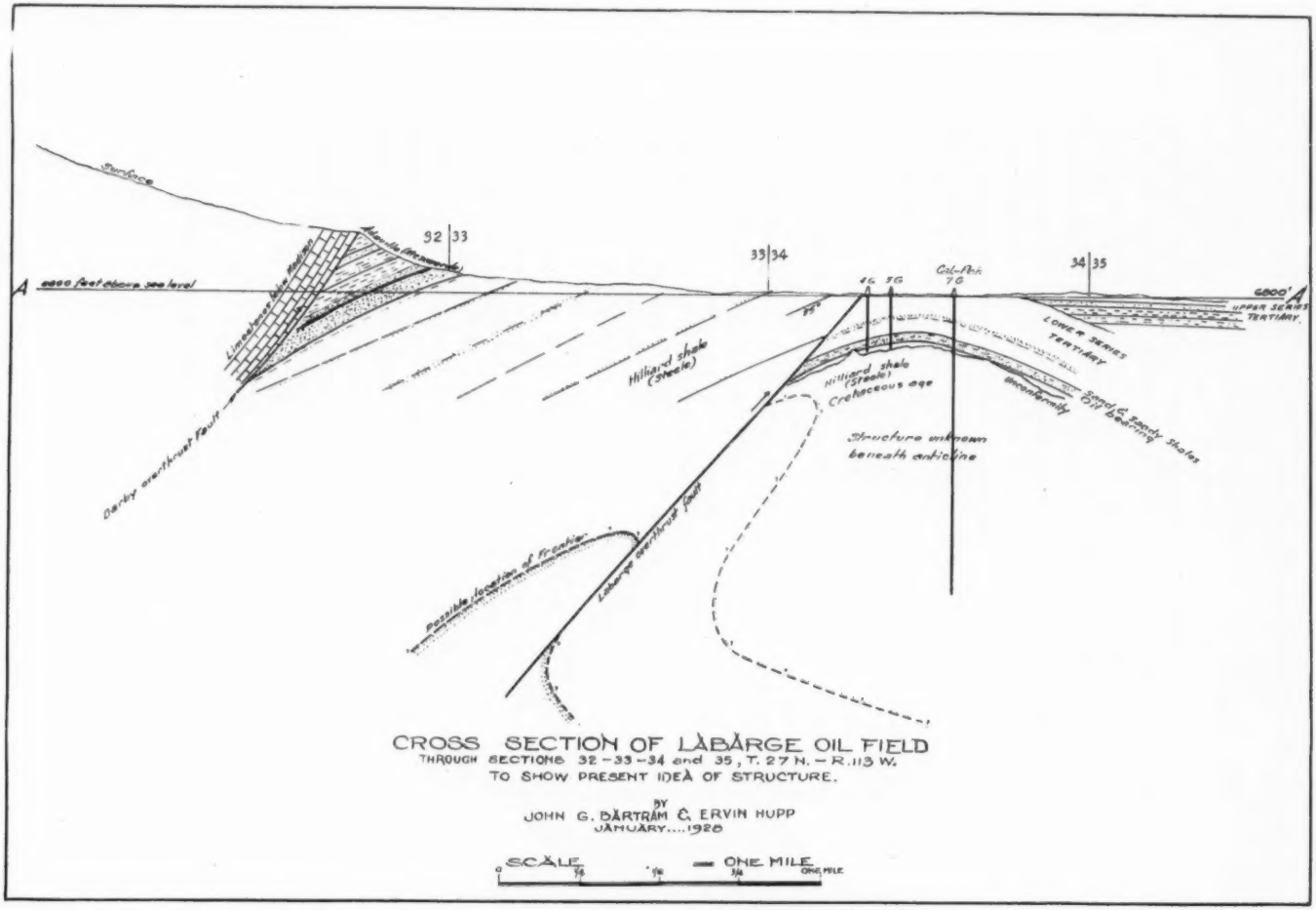


FIG. 7.—La Barge field anticline.

west of the surface axis the beds are vertical. On the east side the average dip is about 30°. After a gas field had been developed in the comparatively shallow "Sharkstooth" sand in the Steele shale, a deep well was commenced to test the Frontier sands. It was located on the surface axis and should have reached the Frontier formation at a depth of almost 3,000 feet if the beds were nearly horizontal. It drilled to 5,200 feet without reaching the sands and a core at the bottom showed a dip of 84°. A survey was not made to determine whether the hole was nearly vertical or not, so that it is possible the 84° dip is not the true dip of the beds, but such a steep dip is entirely within reason on this structure. The well was on the steep side of the anticline and probably missed the crest of the fold in the Frontier formation by at least 800 feet. It should not be a difficult anticline to test, provided proper consideration is given to the steep dips on the west side.

Black Mountain.—The Black Mountain anticline[1] (Fig. 9) in the southeastern end of the Big Horn Basin is another fold of the underthrust type, steep on the southwest side, which dips as steeply as 60°, although the average on the northeast flank is about 15°. Several oil wells have been drilled on the fold, all on the northeast side of the surface axis, the closest being 1,400 feet from the axis. They all appear to be on the low-dip side of the anticline in the Tensleep sand, and the subsurface axis is not yet located with accuracy. The axial plane is believed to be a curved surface that nearly bisects the angle between the two limbs of the fold.

Hudson or Lander.—The Hudson or Lander anticline[2] (Fig. 10) in central Wyoming is an underthrust fold along the east side of the Wind River Mountains. The fold is sharp and narrow, and in places the west side is vertical or overturned, though at the point of the section it is not so steep. The interesting feature is the narrowness of the fold in the Embar and Tensleep formations. Each of these formations is about 300 feet thick, but the well drilled them at such a steep angle that after drilling 1,200 feet below the top of the Embar, it was still in the Tensleep sandstone. The failure to recognize this condition caused considerable confusion among the operators, who first made wrong correlations, and then assumed that the formations had thickened. An examination of the samples revealed that conditions were normal but that the beds were drilled on a steep angle.

[1]D. F. Hewett and C. T. Lupton, "Anticlines in the Southern Part of the Big Horn Basin, Wyoming, *U. S. Geol. Survey Bull. 656* (1917), pp. 123-25.

[2]E. G. Woodruff, "The Lander Oil Field, Fremont County, Wyoming," *U. S. Geol. Survey Bull. 452* (1911).

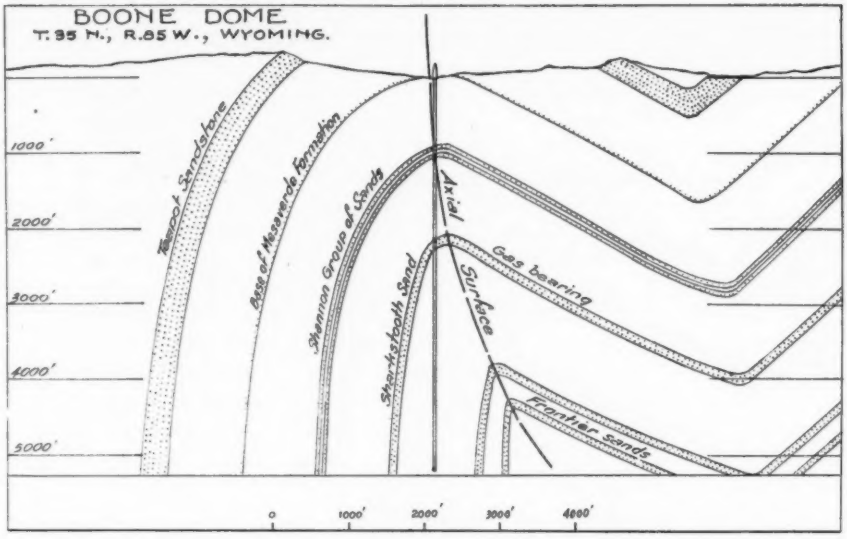


FIG. 8.—Boone dome. Scale in this and following figures, shown in feet.

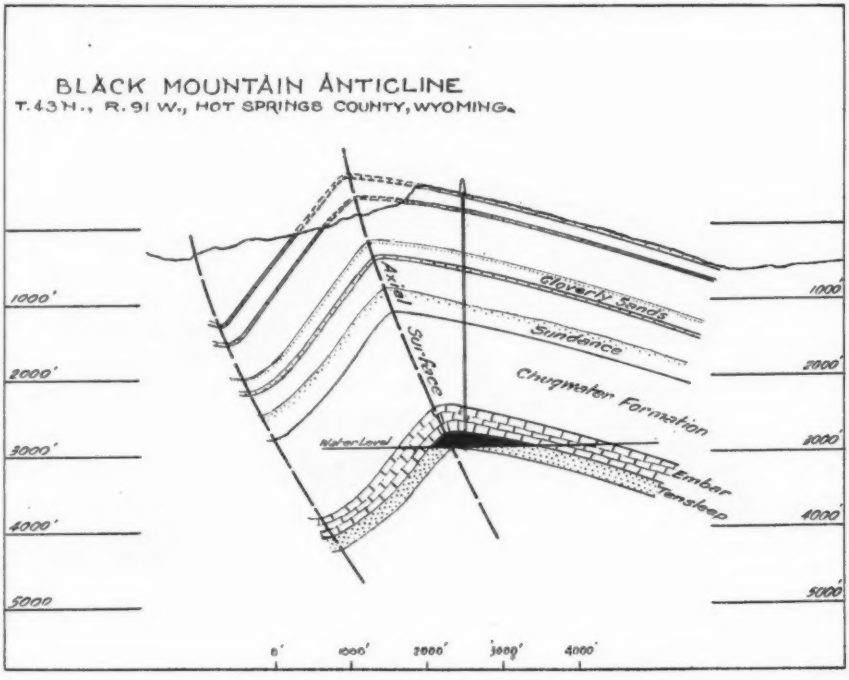


FIG. 9.—Black Mountain anticline.

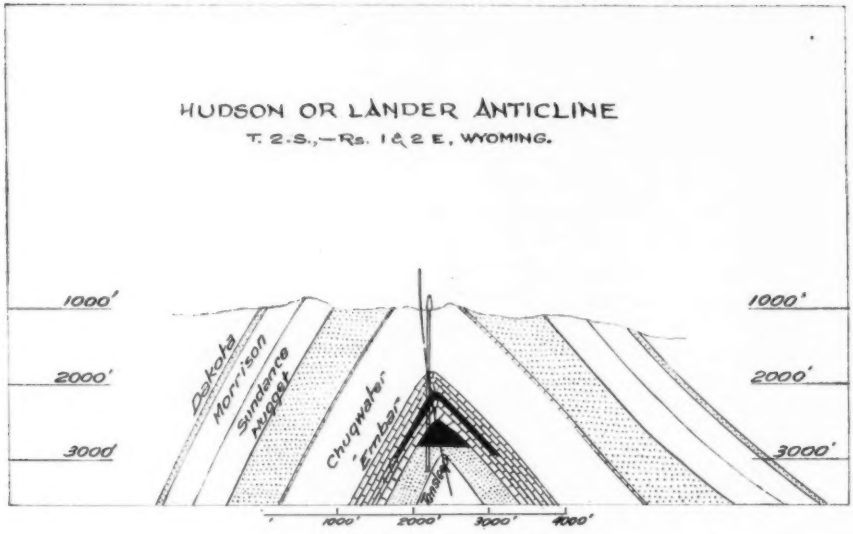


FIG. 10.—Hudson or Lander anticline.

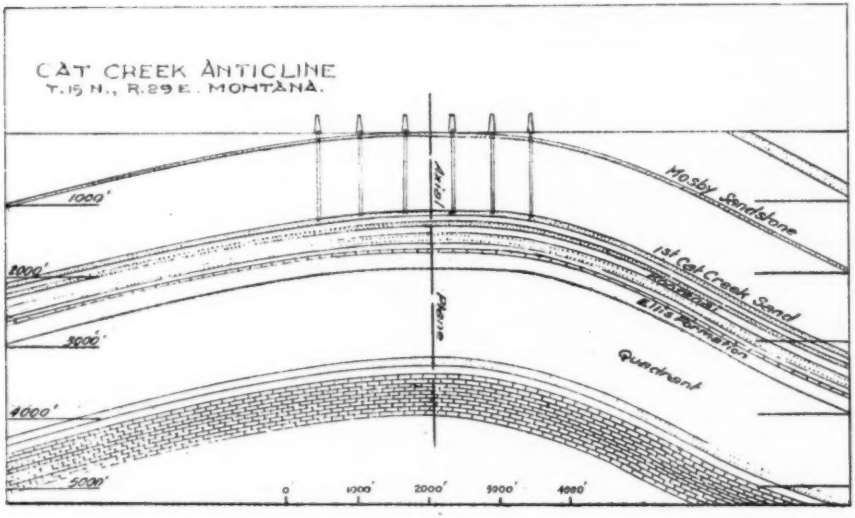


FIG. 11.—Cat Creek anticline.

Cat Creek.—The Cat Creek anticline[1] (Fig. 11) in central Montana has been included because it has frequently been referred to as the exception to the rule that the axis inclines toward the low-dip side. Thom[2] has written than the subsurface axis probably was north of the surface axis, that is, toward the steeper side. The writers have studied the old cross sections of the Cat Creek field, and have drawn new sections. The crest of the fold is so broad and flat that it is extremely difficult, if not impossible, to determine where the axis is in any one bed. The difficulty is increased by the many small normal faults that cut the anticline at right angles to the axis, and on these faults horizontal as well as vertical movement has occurred. On the northeast or steep side the maximum dip is only 30° and on the south side the dip is uniformly 5°. It is predicted that the axial plane at Cat Creek is nearly vertical, and that if there is any inclination, it is toward the low-dip side.

CONCLUSIONS

The most important conclusion is that a thorough knowledge of regional, structural conditions is necessary properly to locate test wells on steep unsymmetrical anticlines. Past mistakes were due largely to a disregard of the fact that the axial plane inclines toward the low-dip side, and to over-emphasizing the local dips near the crest of an anticline. Geologists have bisected the angle formed by the sides of the fold near the axis and assumed that was the angle of inclination. On many anticlines that is correct, but on others the surface dips do not persist with depth. If the outside beds on one side of an anticline are very steep, the axial plane inclines away from that side, and a cross section through the entire structure will be the best help in locating the axis in any horizon below the surface.

Not enough attention has been paid to the angle and course of deep wells in the Rocky Mountains, and almost no wells have been surveyed to determine their actual course. Most of the deep tests are drilled with cable tools, but some of them may be very crooked. The deflection of a deep hole from vertical is very important on steep anticlines and will have to be watched more closely in the future.

[1]C. P. Lupton and W. Lee, "Geology of the Cat Creek Oil Field, Fergus and Garfield Counties, Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5 (1921), pp. 252-75. Frank Reeves, "Geology of the Cat Creek and Devils Basin Oil Fields and Adjacent Areas in Montana," *U. S. Geol. Survey Bull 786-B* (1927).

[2]W. T. Thom, Jr., "The Relations of Deep-Seated Faults to the Surface Structural Features of Central Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), p. 10.

GEORGETOWN FORMATION OF CENTRAL TEXAS AND ITS NORTHERN TEXAS EQUIVALENTS[1]

ROBERT H. CUYLER[2]
Austin, Texas

ABSTRACT

The Georgetown formation in central Texas is 80 feet thick. As it is traced northward the formation is found to thicken to 410 feet at Red River. This total thickness of "Georgetown" in northern Texas is divided into seven formations. In this paper, the writer traces all northern Texas equivalents in order to determine the exact thickness of each of the northern Texas formations included in central Texas Georgetown beds.

The Main Street formation of northern Texas is represented at Austin by approximately 15-20 feet of limestone ledges in the upper one-fourth of the Georgetown formation.

The Pawpaw formation of northern Texas is lacking in the Austin region.

The Weno formation of northern Texas thins, thickens, and again thins southward from Red River and is represented at Austin by approximately 10-15 feet of limestone.

The Denton formation of northern Texas is represented at Austin by only a thin ledge of limestone rich with *Gryphaea washitaensis* Hill.

The Fort Worth formation is the best represented of all northern Texas equivalents of the Georgetown of central Texas, and has approximately 30 feet of Fort Worth sediments at Austin.

The Duck Creek formation of northern Texas is traceable southward to Austin, where its thickness is approximately 30 feet.

The Kiamichi clay of northern Texas becomes decidedly thinner southward and at Austin is represented by only a few feet of shaly marls.

INTRODUCTION

In the past, the Georgetown formation at Austin has been studied considerably, and also much time has been devoted to working in the formations of northern Texas. Although both areas have been worked in detail by geologists of standing, a reliable correlation of the formations of the two localities has been lacking. The purpose of the writer in this preliminary paper is to show which northern Texas formations are equivalent to the Georgetown of central Texas.

Practically all widely separated formations are difficult to correlate. It is a well known fact that in such distances as 200 and 300 miles formations may entirely change in lithology; hence, the only practical means

[1]Read before the Association at the Fort Worth meeting, March 23, 1929. Manuscript received by the editor, March 13, 1929.

[2]Department of Geology, University of Texas.

of correlating such distant formations is by a study of the fossils found therein, or, in other words, it is best to correlate them on the basis of paleontological horizons.

While working on this problem, utmost care has been taken to prevent collecting in places where washed or re-worked material is found, to avoid the "jumping of faults," and to keep all conditions as they should be to insure reliable results.

GEORGETOWN FORMATION IN AUSTIN REGION

The Georgetown formation, the lowest member representing the Washita group in central Texas, is named from the town of Georgetown, where a good exposure of the formation is found on San Gabriel River. Prior to the application of the term Georgetown to the formation, it was called the Fort Worth limestone. The latter terminology was used by Hill and Vaughan.[1]

The Georgetown formation at Austin closely resembles the Fort Worth limestone north of the Brazos, and a study of the two formations reveals that fossils found in the Fort Worth north of Brazos River also occur in the Georgetown of central Texas. Moreover, fossils which belong to the beds both below and above the Fort Worth of northern Texas occur in one formation in the vicinity of Austin, namely, the Georgetown, which in this locality, is approximately one-fifth the total thickness of its equivalents in Cooke or Grayson County.

The Georgetown is ordinarily found east of the Balcones escarpment, and because of disturbances in the Balcones fault zone it is difficult to get a complete section of the Georgetown at any one place, although a fairly complete section was taken south of the Rifle Range at Camp Mabry, just west of Austin. A part of this section, however, was covered.

It is difficult to say that any given section of the Georgetown formation will hold for the entire region around Austin, because many of the marl layers are localized. Some of them seem to be lens-like and may vary in thickness or disappear within a few hundred feet.

The Georgetown formation consists largely of alternating beds of hard, impure, white limestones and beds of marls or marly clays. Before exposure and weathering, the limestone is hard and has a blue color, but after weathering it is yellowish-white, some parts becoming nodular.

The basal 13 feet of the formation at Austin is characterized as a rather soft, chalky limestone. Above this occur about 33 feet of alternating beds of yellowish, hard and soft material. It is in this division of

[1] R. T. Hill and T. W. Vaughan, *U. S. Geol. Survey 18th Ann. Rept.*, Pt. 2 (1897).

the section that most of the fossils are found. This middle part of the section looks very much like the Fort Worth formation of northern Texas, and has in it the characteristic fossils of that formation; hence, we may see the reason why the present Georgetown formation was called the Fort Worth limestone. Above this alternating material may be found a bed of reddish or yellow calcareous shale which is approximately 4 feet thick. Hard, marly material, yellow in color after exposure, is next encountered for approximately 9 feet. The top of the Georgetown at Austin is marked by a hard, massive, blue limestone which caps some of the hills around Austin.

NORTHERN TEXAS EQUIVALENTS OF THE GEORGETOWN

Table I shows the variation in thickness in the counties concerned and illustrates the fact that the formations change very rapidly in thickness.

As has been mentioned before, the most reliable method of correlating the formations of these localities which are far removed from one another is the comparison of their fossils. It is necessary, therefore, to list the fossils in each locality in sequence and then observe how the several sections grade into one another. A paleontological correlation of the Red River and Austin sections is given in Figure 2.

In tracing the northern Texas formations southward, it is at once noticed that the formations consisting of soft, unconsolidated materials thin the most rapidly. For example, the Denton and Pawpaw formations, composed of soft, unconsolidated sediments having a total thickness of approximately 110 feet in Cooke or Grayson County, are reduced to approximately 10 feet at Brazos River.

In making the preceding statement the writer does not wish to leave the impression that the thinning occurs only in formations of a soft nature. The thicknesses of the harder formations are likewise reduced from 365 feet on Red River to 75 feet at Austin.

Kiamichi clay.—Since the first literature was printed concerning the formations of northern Texas, the Kiamichi clay has been considered as being the lowest formation in the Washita group. In reality, instead of being in the Washita group, the formation could equally as well be included in the Fredericksburg group because of the characteristic Fredericksburg fauna which it bears. For this reason the Kiamichi clay will not be considered strictly as one of the Georgetown equivalents but as a transitional formation between the Fredericksburg and Washita groups.

TABLE I

RELATIVE THICKNESS OF THE WASHITA GROUP AND THICKNESS OF GEORGETOWN EQUIVALENTS, IN FEET, IN DIFFERENT COUNTIES

County	*Thickness of Washita Group*	*Thickness of Georgetown Equivalents*	*Duck Creek*	*Fort Worth*	*Denton*	*Weno*	*Pawpaw*	*Main Street*	*Grayson*
Cooke or Grayson	410	375	100	45–60	45–60	100	50	10–20	30
Denton	380	305	100	25–35	25–35	65–105	35–50	15	75
Tarrant	325	250	65	25	20–25	65–70	27–40	35–40	75
Johnson	267	167	20	25–27	25	40	9	50	100
McLennan	225	155	30	30	5	50	5	35	Del Rio 70
Travis	200	80	25	30	2	10–15	0	15–20	Del Rio 80

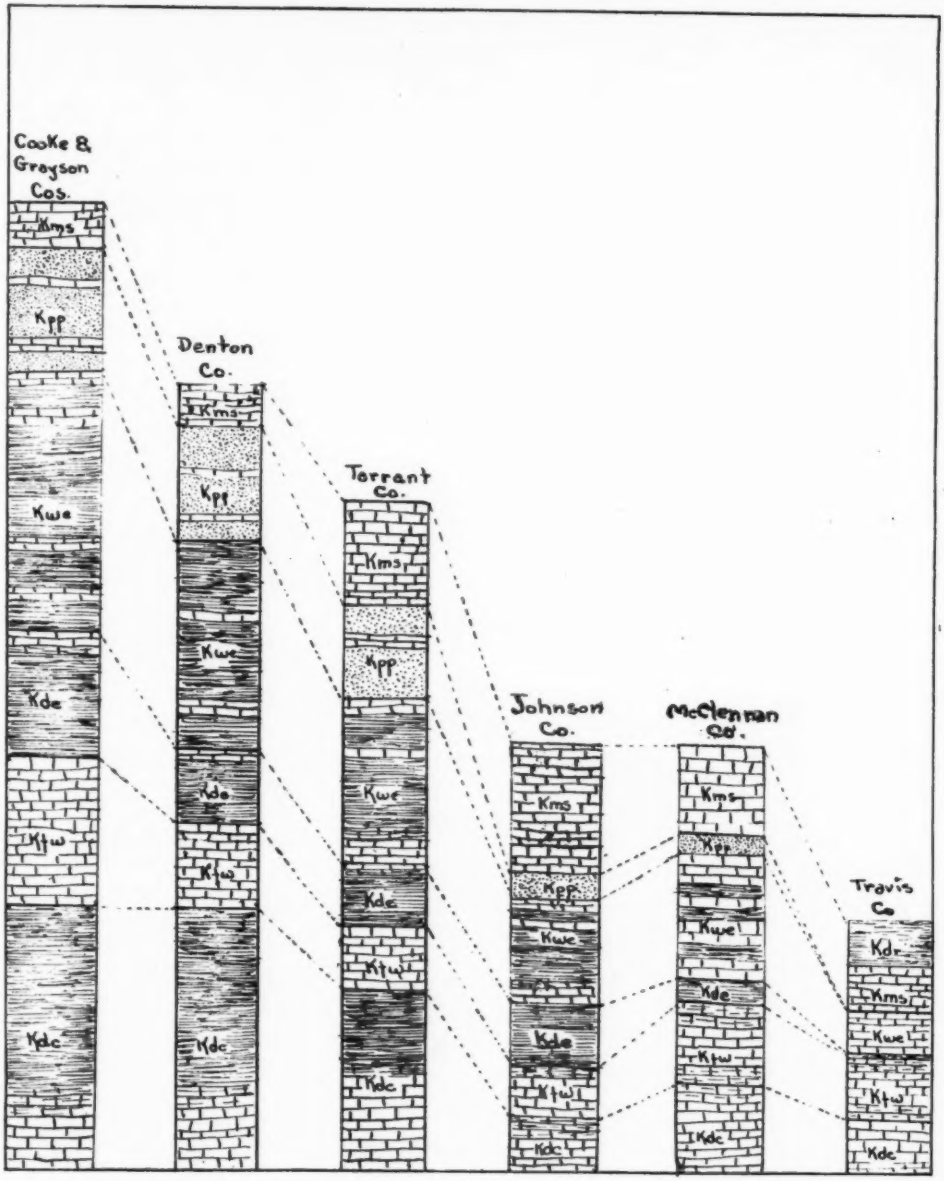


FIG. 1—Chart showing stratigraphic relations of Upper Cretaceous series of central Texas.

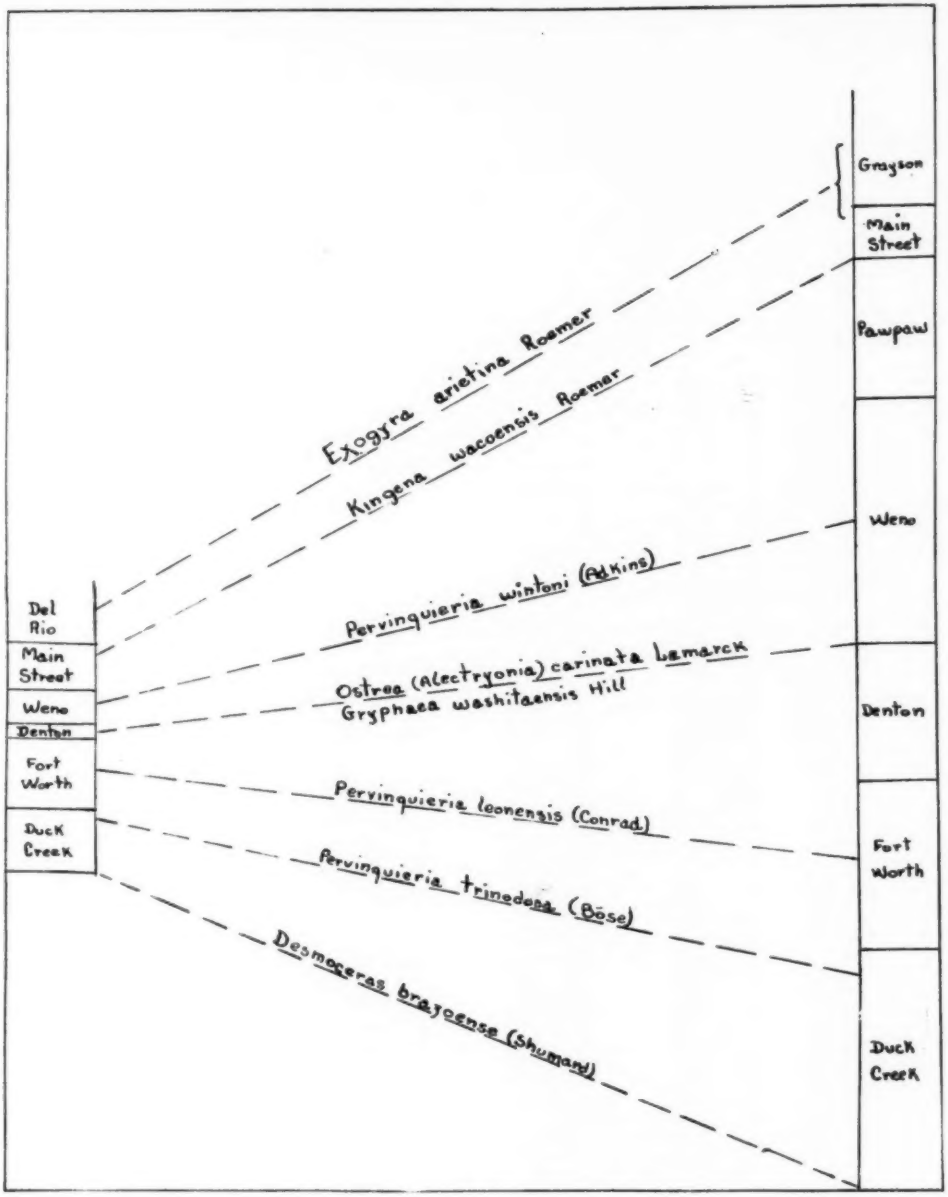


FIG. 2.—Paleontological correlation of the Austin and Red River sections.

Duck Creek formation.—The Duck Creek formation of northern Texas thins uniformly from Red River to Colorado River, the marl members disappearing. It is, therefore, the limestone member which is best represented in the central Texas Georgetown as the equivalent of the northern Texas Duck Creek.

The Duck Creek is more easily traced southward from Red River than the other formations because the Duck Creek has some typical fossils which can not readily be mistaken. Among these fossils are *Desmoceras brazoense* (Shumard), *Pervinquieria trinodosa* (Böse), and *Hamites comanchensis* Adkins and Winton.

On San Gabriel River at Georgetown, Williamson County, *Desmoceras brazoense* (Shumard) occurs, and at Round Rock, about 18 miles north of Austin, the Duck Creek may be seen in part with numerous specimens of *Pervinquieria trinodosa* (Böse). At Austin, the Duck Creek formation is represented by approximately 20 feet of hard white limestone containing few fossils, among which are *Pervinquieria trinodosa* (Böse), *Desmoceras brazoense* (Shumard), and *Gryphaea washitaensis* Hill.

Fort Worth formation.—The Fort Worth formation at Austin retains its northern Texas appearance more than any other equivalent of the Georgetown. The Fort Worth limestone resembles the whole of the Georgetown limestone of central Texas, and for a time the Georgetown formation was called the Fort Worth limestone. At Austin, the Fort Worth is approximately 30 feet thick and consists of alternating beds of limestone and marl. *Pervinquieria leonensis* (Conrad), *Macraster elegans* (Shumard), *Holaster simplex* Shumard, *Exogyra americana* Marcou, *Ostrea* (*Alectryonia*) *carinata* Lamarck, and *Gryphaea washitaensis* Hill are all well represented in the equivalent of the Fort Worth in the Georgetown at Austin.

Denton marl.—The Denton marl is one of the formations consisting of soft, unconsolidated material. It is approximately 55 feet thick on Red River, but at Waco it is only about 5 feet thick. At Georgetown, the Denton is represented by a bed with *Gryphaea washitaensis* Hill in profusion. This bed is between 2 and 3 feet thick and is also found at Austin with this same thickness.

Weno formation.—The Weno formation, which in Tarrant County is 65-70 feet thick, is 50 feet thick in McLennan County and only 10 or 15 feet thick at Austin. On San Gabriel River at Georgetown a complete section of the Weno is exposed. The Weno at this locality consists of alternating beds of soft limestone and thin shaly marl. At Austin it has the same nature lithologically and contains typical Weno fossils including

Trigonia clavigera Cragin, *Neithea georgetownensis* Kniker, *Nautilus texanus* Shumard, and in a few places *Pervinquieria wintoni* (Adkins).

Pawpaw formation.—The Pawpaw formation is very impure and is made up essentially of sands and sandy clays. This formation consists of near-shore deposits; hence, it is variable in the nature of its deposits. The formation as a whole is distinctly ferruginous, thus giving a yellowish or brownish color to the clays upon weathering.

One of the most striking facts about the Pawpaw formation is the pronounced thinning which it exhibits to the south from Red River to Brazos River. It is to be noted that along Red River the formation is between 50 and 60 feet thick, whereas, at Brazos River, it disappears entirely. The formation becomes more argillaceous southward from Red River, clays in the southern area extensively replacing the sands of the northern territory.

Main Street formation.—The Main Street consists of calcareous clays and limestones which are white to yellow in color. An interesting thing to note about the Main Street is that instead of thinning toward the south between Red River and Brazos River, this formation thickens. All of the other formations below the Main Street in the Washita group of northern Texas become thinner as they are traced southward. The Main Street formation is especially interesting because of the fact that in central Texas one part of the Main Street grades into the Del Rio clay, whereas another is included in the Georgetown formation. The base of the Main Street contains the horizon of *Kingena wacoensis* Roemer; whereas, the upper part contains *Exogyra arietina* Roemer in abundance. These fossils become, therefore, the index fossils of the Georgetown and Del Rio, respectively.

SUMMARY

1. The Main Street formation of northern Texas is represented at Austin by approximately 15-20 feet of limestone ledges in the upper one-fourth of the Georgetown formation.

2. The Pawpaw formation of northern Texas is lacking in the Austin region.

3. The Weno formation of northern Texas thins, thickens, and again thins southward from Red River and is represented at Austin by approximately 10-15 feet of limestones.

4. The Denton formation of northern Texas is represented at Austin by only a thin ledge of limestone with a great many specimens of *Gryphaea washitaensis* Hill.

5. The Fort Worth formation is the best represented of all of the northern Texas equivalents of the Georgetown formation of central Texas, about 30 feet of Fort Worth sediments occurring at Austin.

6. The Duck Creek formation of northern Texas is traceable southward to Austin, where its thickness is approximately 30 feet.

7. The Kiamichi clay, heretofore considered, on a basis of its lithologic characters, as belonging to the Washita group, is now considered, because of its characteristic Fredericksburg fauna, as a transitional formation between the two groups.

STRUCTURAL FEATURES OF WEST FRANKLIN FORMATION OF SOUTHWESTERN INDIANA[1]

ROBERT R. SHROCK[2] and CLYDE A. MALOTT[2]
Madison, Wisconsin, and Bloomington, Indiana

ABSTRACT

The West Franklin limestone formation, occurring about 300 feet above Coal V, 900 feet above the base and 350 feet below the top of the Pennsylvanian, in southwestern Indiana, is used in this paper to determine the structural conditions in its outcrop area. It is traced into Illinois on the north and into Kentucky on the south. The regional structure conforms with the general southwesterly dip shown by all of the formations in southwestern Indiana. In the southern part of the outcrop area, however, the uniform regional dip is locally complicated by small low domes or anticlines and shallow basins or synclines. These small structures are thought to have been formed by differential settling and compacting of muds and other sediments over and about bodies of sand.

INTRODUCTION

It is the purpose of the writers to give a brief discussion of the structural features of a part of southwestern Indiana as indicated by data on the West Franklin formation. This double-bedded limestone formation has been referred to, in Indiana, by different writers as Productal limestone, Double limestone, Argillaceous or Bituminous limestone, West Franklin limestone, and Somerville limestone. The name West Franklin was the first geographic name proposed.[3] Hence in compliance with the generally accepted rules of priority, the writers use that name rather than Somerville, which was proposed at a later date by the geologists of the United States Geological Survey[4] for identically the same forma-

[1]Presented before the Association at the Fort Worth meeting, March 21, 1929. Manuscript received by the editor, April 22, 1929.

[2]Introduced by W. H. Twenhofel.
The information presented in this paper was obtained by the writers during the summers from 1924 to 1928. The detailed map (Fig. 3) was made chiefly from data collected in the summer of 1924. The work was carried on through a joint agreement between The Pure Oil Company of Columbus, Ohio, and the Conservation Commission (Division of Geology) of Indiana. All subsequent work has been carried on chiefly at the expense of the writers. Several small grants by the Waterman Institute for Scientific Research at Indiana University should be mentioned in this connection.

[3]J. Collett, *13th Indiana Report* (1884), pp. 61-62.

[4]M. L. Fuller, "Ditney Folio, Indiana," *U. S. Geol. Survey Geol. Atlas, Folio 84* (1902), p. 2.

tion. In a detailed paper on the West Franklin formation, now in preparation, a complete discussion of the question of nomenclature will be included.

Character of the formation.—The West Franklin formation consists of a lower, hard, blue to gray, brecciated limestone member whose average thickness is about 5 feet; a middle shale member which is variable in thickness (maximum, 25 feet) as well as in lithologic character; and an upper, dense, gray crystalline limestone member whose average thickness is about 3 feet. The upper member is only very rarely brecciated. Both limestone beds are somewhat fossiliferous, but with one exception no fossils have been found in the shale. A thin coal bed with accompanying black thinly-laminated shale marks the shale member in many localities.

In many places only one of the limestone members is present, the other being absent either because of lack of deposition, as would be true if the lower were absent and the upper present, or because of removal by erosion subsequent to deposition, as would be true if the lower were present and the upper, and perhaps also the shale member, absent. Only in one place was the upper member found resting directly on the lower with the middle or shale member entirely absent. The shale is ordinarily present where the upper member is present and the lower either absent or represented by a calcareous nodular shale, but in many places it is missing where the upper member is absent and the lower present. In the last condition it may be difficult if not impossible to distinguish between the shale member of the West Franklin formation and the shale formation which separates the West Franklin from the overlying Merom sandstone. A period of erosion preceded the deposition of the Merom sandstone, so that in many places much, if not all, of the underlying shale formation is removed, and where erosion was extreme, part or all of the West Franklin formation is gone, and the Merom rests disconformably upon the shale-sandstone sequence immediately underlying the West Franklin.

Obviously, therefore, much discretion had to be used in interpreting the available structural data. In structural determinations the top of the lower member of the West Franklin formation was used as a datum. In its absence either the residual clay resulting from its decomposition, or the interval between it and the upper member, were used to reduce the elevations to one plane. In a very few places, where the entire formation is absent, the Merom sandstone was found resting on the shale series below the West Franklin and the contact between the shale and the over-

lying sandstone was used, with the necessary limitations, to approximate the elevation of the lower member.

Stratigraphic relations.—The West Franklin formation is approximately 900 feet above the base of the Pennsylvanian and about 350 feet below the highest Pennsylvanian formation in Indiana. It consistently occurs 300 feet above Coal V, which, with its superincumbent black shale and limestone, is the most prominent and widespread stratigraphic marker in the Coal Measures of the Eastern Interior coal field. This interval may decrease to 280 feet or increase to 315 feet or slightly more, because of the local thinning or thickening of the intervening strata. Such a variation is commonly found in the Pennsylvanian strata of southwestern Indiana; hence, it is to be expected.

The formation is a serviceable marker in wells and shows in most of the wells in the region down the dip from the outcrop. It is almost everywhere underlain by a series of thin sandstones and sandy shales. A shaly or laminated, or more rarely a thin-bedded sandstone almost everywhere occurs about 15 or more feet below the base of the formation. This common sandstone bed is rather resistant to weathering and erosion and is conspicuous because it ordinarily causes small waterfalls and cascades where the smaller streams cross it. Immediately overlying the West Franklin is a shale and sandstone formation which ranges in thickness from a few feet to 30 feet. In many places a thin coal is present in this formation. In most exposures, however, much of the formation is gone, having been eroded before the deposition of the overlying Merom sandstone.

The Merom sandstone in its exposures is characteristically a yellow, very friable, coarse-grained, highly cross-bedded, mica-bearing sandstone, 20 to 60 feet in thickness. In a few places it has been found to be 80 feet or more in thickness, but not in continuous exposure. Its disconformable base is made conspicuous by a thin conglomerate cemented by iron, some of which is in concretionary form. In some localities, however, these conspicuous characteristics of the Merom are lacking and the formation is composed of gray sandstone beds with much sandy shale, and it is difficult to distinguish it from other sandy formations commonly present in the Pennsylvanian of southwestern Indiana. It has been found resting on the shale and sandstone formation overlying the West Franklin formation, resting disconformably on the upper, middle, or lower members of the West Franklin, and in a very few places even resting on the series of shales and sandstones below the West Franklin.

This sandstone is ordinarily conspicuous in well logs and is of considerable assistance in identifying the West Franklin, because it is so consistently found either immediately above that formation or separated from it by only a few feet of shale, or shale and sandstone.

The following records show the character of the strata above the West Franklin formation and also between that formation and Coal V.

TABLE I

RECORD OF THE HAGEMANN WELL

Location: N.½ Sec. 33, T. 6 S., R. 12 W., Posey County, about 7½ miles southwest of Evansville and about 8½ miles northeast of Mt. Vernon. W. N. Logan, "The Geology of the Deep Wells of Indiana," *Conservation Commission, Division of Geology, State of Indiana, Publication 55* (1926), pp. 473-74. Elevation, 485 feet above sea-level. Interpretations by the writers.

Formation	*Thickness in Feet*	*Depth in Feet*
Clay	14	14
Sandstone, soft	24	38
Limestone, fresh water } Parker	5	43
Limestone } Parker	2	45
Shale, white (Merom)	95	140
Limestone (West Franklin)	5	145
Shale	15	160
Shale, sandy	35	195
Shale, black	25	220
Shale, calcareous	5	225
Shale, black	35	260
Limestone and shale	5	265
Shale, brown	5	270
Trace of coal	..	..
Shale	5	275
Limestone and shale	5	280
Shale	60	340
Limestone	5	345
Trace of coal	..	..
Shale, white	75	420
Limestone, very hard	7	427
Sandstone	8	435
Shale, white	22	457
Limestone, very hard	5	462
Coal (Coal V)	7	469
Shale, brown, soft	11	480

TABLE II

WELL NO. 3 (R. HOWE FARM)

Location: SE. of NW. ¼ Sec. 1, ¼ mile north of old coal mine in N. part of Princeton. Log furnished by J. G. Applegate.

Formation	*Thickness* Feet	Inches	*Depth* Feet	Inches
Surface and sand	19		19	
Sandy shale	13		32	
Sandstone (Merom)	31	6	63	6
Coal	0	1	63	10
Fireclay	3	2	67	
Sandy shale	9		76	
Limestone (West Franklin)	6		82	
Light sandy shale	5		87	
Sandy slate	8		95	
Blue kidney shale	28	3	123	3
Coal	0	9	124	
Sandstone	4		128	
Sandy shale	9		137	
Sandy slate	37		174	
Sandstone	8		182	
Dark slate	2		184	
Limestone	4		188	
Sandy slate	12		200	
Sandstone	12		212	
Limestone	5		217	
Sandstone	32		249	
Sandy slate	15	9	264	9
Draw slate	0	3	265	
Coal	1	6	266	6
Dark slate	1	6	268	
Sandstone	104		372	
Brown slate	5		377	
Limestone	6		383	
Black slate	2	2	385	2
Coal (Coal V)	3		388	2
Fireclay	2	4	390	6
Sandstone	64		454	6
Sandy shale	1	6	456	
Sandstone	4		460	
Brown slate	24		484	
Black slate	3	9	487	9
Coal	1	6	489	3
Sandstone	2	9	492	

The following section was measured in the river bluff from West Franklin eastward to Priest's Bluff—a distance of slightly more than a mile.

The former locality is the type section of the West Franklin formation.

TABLE III

SECTION BETWEEN WEST FRANKLIN AND PRIEST'S BLUFF

		Thickness in Feet
10.	Soft, yellow, massive micaceous sandstone (typical Merom sandstone) *Disconformity*	20
9.	Hard, laminated to massive, yellowish to gray sandstone	10
8.	Sandy gray shale	10
7.	Dense, crystalline, massive, gray to yellowish limestone, with some fossils. (Upper member of the West Franklin)	3-7½
6.	Gray shale with a thin coal and black thinly laminated shale full of *Hemipronites crassus*. The coal and black shale are absent at Priest's Bluff. (Middle member of the West Franklin)	5-5½
5.	Gray, brecciated, fossiliferous limestone. Thins and becomes quite nodular in the Priest's Bluff section. (Lower member of the West Franklin)	5-10
4.	Light colored shale	2½
3.	Laminated sandstone becoming somewhat massive at the top. Surfaces conspicuously ripple marked	8
2.	Gray shale with nodular sandstone masses. Changes laterally to a laminated sandstone	8
1.	Bluish-gray shale with layers of iron carbonate concretions (to low water level in Ohio River)	50
	Total	121½-131½

A careful study of this section shows marked lithologic and faunal changes in the strata both laterally and vertically. Especially conspicuous are the disconformity at the base of the Merom sandstone and the thinning of the members of the West Franklin eastward.

Outcrop area.—The West Franklin formation crops out in a sinuous line extending from the village of West Franklin on Ohio River southwest of Evansville in a northerly direction almost to Terre Haute (Figs. 1 and 2).

Starting at West Franklin the line of outcrop extends diagonally across Vanderburg County, thence northward through Gibson County, with isolated outliers on the east in the extreme eastern part of the county and in the northwestern corner of Warrick County, thence northward through central Knox County, thence slightly to the northwest through western Sullivan and southwestern Vigo counties, reappearing in Illinois in central-eastern Clark County. The line of outcrop also crosses from Indiana into Illinois in northeastern Knox County where it swings across the Wabash in a gentle curve just south of Palestine, Illinois.

South of Princeton outcrops are numerous and the outcrop can be traced with reasonable accuracy, but north of that city, due to the heavy

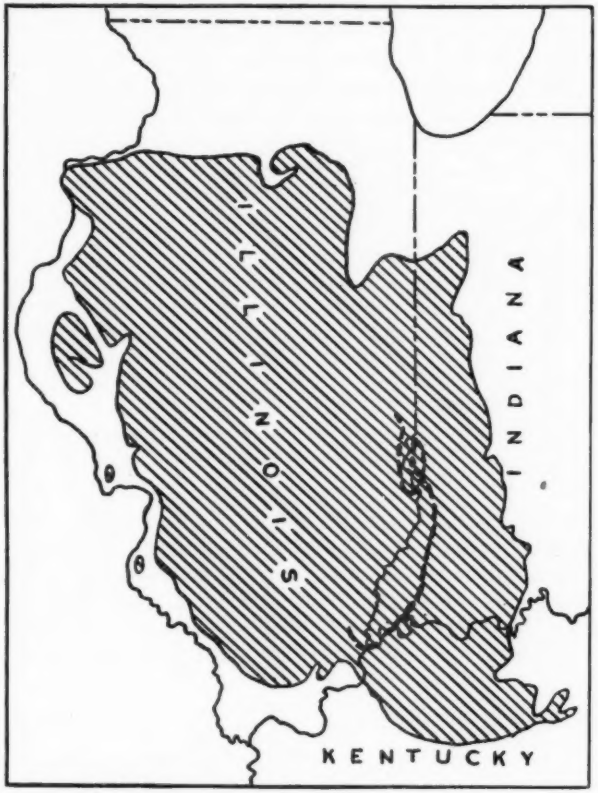


FIG. 1.—Outline map of the Eastern Interior coal basin showing the outcrop line of the West Franklin limestone in southwestern Indiana.

mantle of glacial drift on the one hand and the broad valley of the Wabash River on the other, outcrops are few and ordinarily are a considerable distance apart.

Age and correlation.—The West Franklin formation is of post-Allegheny age. Southwestward from the type section at West Franklin, Indiana, it is found exposed in the banks of Ohio River below Uniontown, Kentucky, at the Middle and Lower Highlands Reefs. It extends far-

ther southwest, rising more than 100 feet to Grundy Knob on the south.[1]

Farther north, the West Franklin formation, which is well developed in the high river bluff at Merom, Indiana, is exposed a short distance southwest of Merom in the hills southeast of Palestine, Illinois (Fig. 2). From the outcrops in southwestern Vigo County, Indiana, it is only a short distance northwest to Ashmore and Big creeks, in central-eastern Clark County, Illinois, where the West Franklin is well developed and is overlain by a great thickness of typical Merom sandstone.

The similarity of the New Haven limestone of Illinois, and the sequence beneath, to the West Franklin and subjacent formations of Indiana, might suggest that both are of the same age, but it is more probable that the New Haven is a higher formation. This correlation, which must be settled by careful field work, was made long ago by Cox[2] and later by Udden.[3]

REGIONAL STRUCTURE

The strike, like the outcrop, approximately parallels the eastern boundary of the Eastern Interior coal basin (Figs. 1 and 2).

Toward the south the structure contours change to an east-west trend, paralleling the Rough Creek fault. In the northern part of the area near Merom, the structure contours double back, indicating a syscline north of Vincennes and a possible terrace structure west of Sullivan. This terrace structure may in part account for the oil production in the several small fields northwest of Sullivan. Elsewhere throughout the area the general strike is north-south and the dip is in a general westerly direction at about 25 feet per mile.

[1]This interpretation is not in accord with that of Lee ("Geology of the Kentucky Part of the Shawneetown Quadrangle," *Kentucky Geol. Survey* (1916), p. 53) who states, "North of the Rough Creek fault the structural deformations are much more gentle. From Spring Grove, where the Herrin coal outcrops, the beds dip west of north at the rate of about 125 feet to the mile. Toward the east, outside the area, the dip of the beds seems to be east or northeasterly. The coals at Morganfield, 5 miles distant, are 225 feet lower than those near Spring Grove, and at Uniontown, 3½ miles northeast of the quandrangle, the coals are 100 feet lower than at Spring Grove but nearly 300 feet higher than at Grundy Knob. These facts suggest that a pitching anticline extends northeastward from the vicinity of Spring Grove toward Uniontown." He also states (page 39) that the limestone exposed on Grundy Knob is 590 feet above Coal No. 9 (Coal V of Indiana) and that it is probably higher than the limestone outcropping in the river bank below Uniontown. Finally, his structure map does not seem to be consistent with either of the preceding statements. The writers consider the limestone formations at West Franklin, in the river bank below Uniontown, and on Grundy Knob as being of the same age, and they present structural and stratigraphic data to support this statement in a detailed paper now in preparation.

[2]"Geology of Gallatin County," *Geol. Survey of Illinois*, Vol. 6 (1875), p. 212.

[3]"Notes on the Shoal Creek Limestone," *Geol. Survey of Illinois Bull. 8* (1907), p. 118.

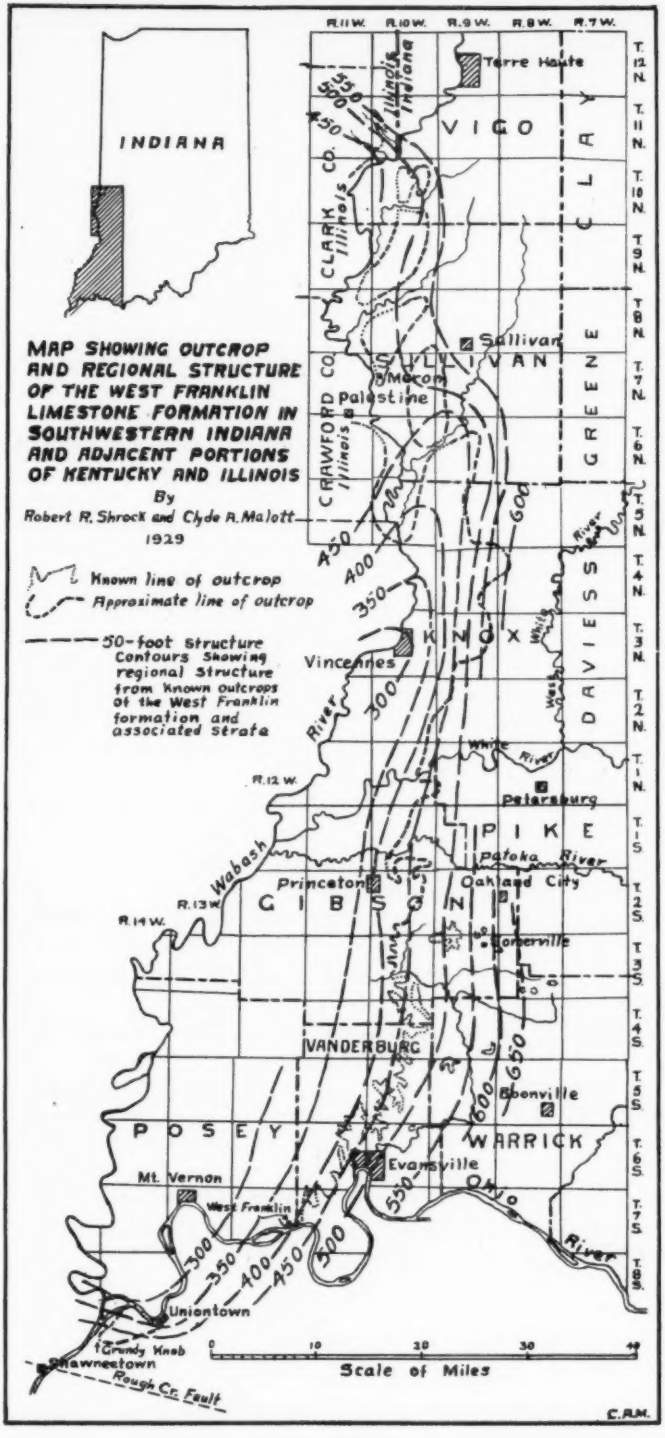

INDIANA
MAP SHOWING OUTCROP AND REGIONAL STRUCTURE OF THE WEST FRANKLIN LIMESTONE FORMATION IN SOUTHWESTERN INDIANA AND ADJACENT PORTIONS OF KENTUCKY AND ILLINOIS
By
Robert R. Shrock and Clyde A. Malott
1929
Known line of outcrop
Approximate line of outcrop
50-foot structure Contours Showing regional structure from known outcrops of the West Franklin formation and associated strata
R.11W. R.10W. R.9W. R.8W. R.7W.
Terre Haute
VIGO
CLAY
CLARK Co. Illinois
CRAWFORD Co. Illinois
SULLIVAN
GREENE
Sullivan
Merom
Palestine
DAVIESS
KNOX
Vincennes
White River
Wabash River
PIKE
Petersburg
Patoka River
Princeton
Oakland City
GIBSON
Somerville
VANDERBURG
Ebenville
POSEY
WARRICK
Evansville
Mt. Vernon
West Franklin
Ohio River
Uniontown
Grundy Knob
Shawneetown
Rough Cr. Fault
450
500
550
600
650
400
350
300
0 10 20 30 40
Scale of Miles
C.A.M.

FIG. 2

DETAILED STRUCTURE

The general stratigraphic and structural setting for the West Franklin formation having been given, it remains to point out some of the irregularities of the structure contours and what these irregularities may indicate.

Since numerous producing structures in southwestern Indiana are known to be small both in size and closure, closures of 20 feet or more are worthy of consideration as possible oil and gas reservoirs.

The reader, in considering the following descriptions, should follow closely the detailed map (Fig. 3).

From West Franklin to Evansville the beds strike northeast-southwest and dip rather uniformly (about 25 feet to the mile) toward the northwest. The data upon which the contours for this area are based were obtained with aneroid barometers; hence, the lines may vary slightly from absolute accuracy. From Evansville northward all data were obtained with a planetable and telescopic alidade.

Near the northern parts of Sections 22 and 23, T. 6 S., R. 11 W., a shallow syncline with an east-west trend flanks the narrow sinuous anticline which extends from the northern part of Evansville northwest and north to the northern part of Sec. 2, T. 6 S., R. 11 W. Approximately paralleling this anticline on the north is a shallow syncline which separates the anticline from the broad terrace-like structure, with two small domes, in the vicinity of Highland and Zipp.

At McCutchanville a small nose is present, flanked on the east and west by shallow synclines in Sections 27 and 34, T. 6 S., R. 10 W., and Sections 20, 21, 28, and 29, T. 6 S., R. 11 W., respectively.

One and one-half miles southwest of Elliott, in Sec. 2, T. 5 S., R. 10 W., the north end of an apparent anticline is present. Owing to inadequate data, the complete outline of this structure could not be determined. It is flanked on the west by a rather sharp syncline with a general north-south trend.

In Sections 23, 24, 26, and 27 a broad anticline is present, flanked on both the west and south by synclines.

The syncline shown in Sec. 35, T. 3 S., R. 10 W., is somewhat of a puzzle. Certain features about the outcrops in its vicinity indicate the possibility of a small fault, but it seems best to consider the structure as a sharp synclinal flexure. This syncline is separated from a shallow depression on the west by a narrow anticlinal ridge beginning in Sec. 11, T. 4 S., R. 10 W., and continuing in a northerly direction to Sec. 26, T. 3 S., R. 10 W.

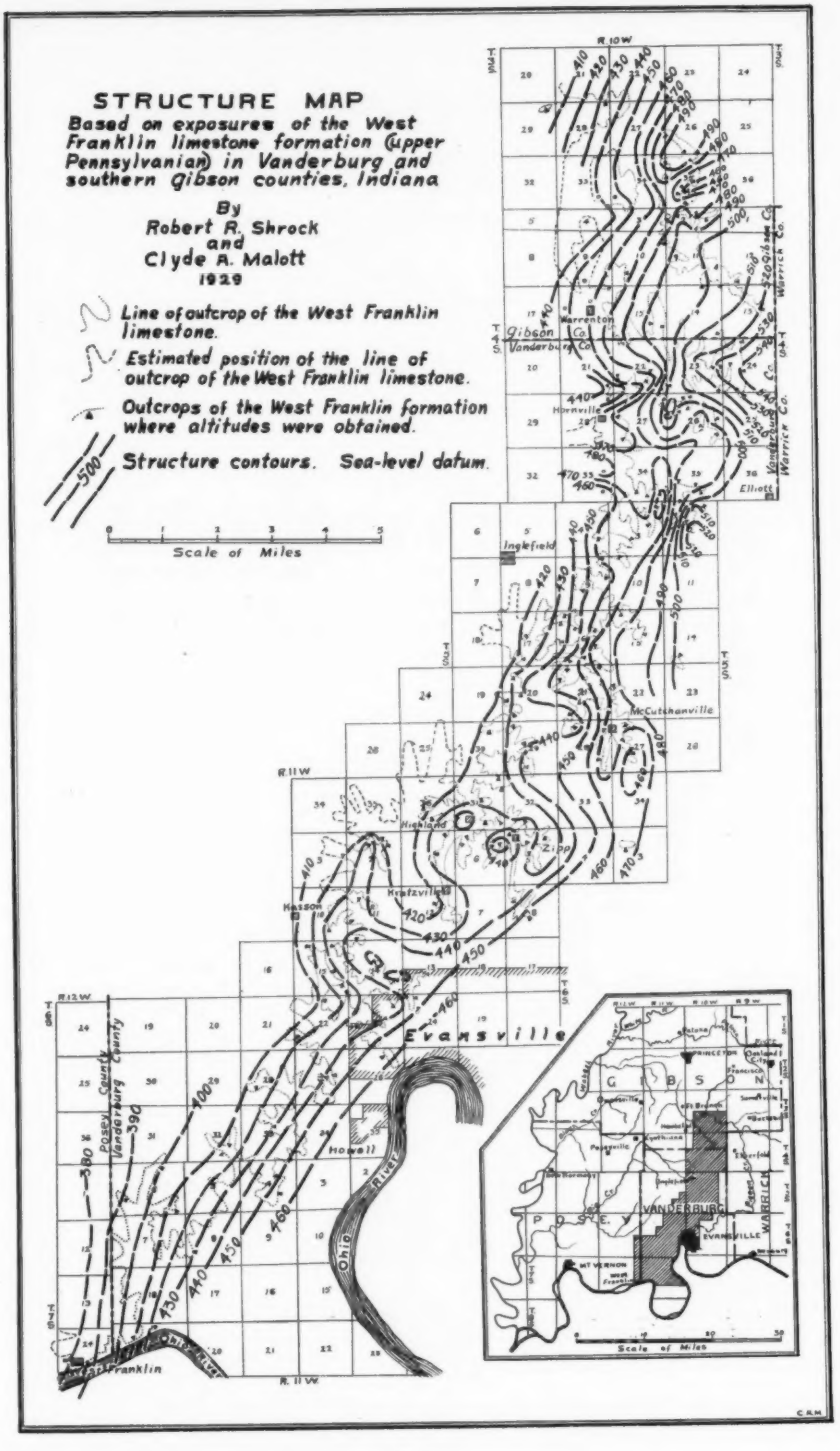

STRUCTURE MAP
Based on exposures of the West Franklin limestone formation (upper Pennsylvanian) in Vanderburg and southern Gibson counties, Indiana
By
Robert R. Shrock
and
Clyde A. Malott
1929
Line of outcrop of the West Franklin limestone.
Estimated position of the line of outcrop of the West Franklin limestone.
Outcrops of the West Franklin formation where altitudes were obtained.
Structure contours. Sea-level datum.
Scale of Miles
R.10W
R.11W
R.12W
Evansville
Mt. Vernon
Howell
Ohio River
Warrenton
Hornville
Inglefield
McCutchanville
Highland
Kratzville
Hasson
Zipp
Elliott
Princeton
Vanderburg
Posey
Gibson
Warrick

FIG. 3

If more detailed data were available for the area between West Franklin and Evansville, it is very probable that the general uniform dip shown on the map would be complicated by small domes and basins similar to those on the north.

ORIGIN OF THE STRUCTURES

It is hardly necessary to state that the regional dip of the geological formations of southwestern Indiana is caused by their situation on the west flank of the Cincinnati arch. Little of the general dip of the formations may be regarded as initial. The larger structural and regional relationships indicate that the regional dip is dependent almost wholly on the diastrophic movements which resulted in the making of the Indiana-Illinois coal basin and the Cincinnati arch.

Locally, however, as indicated by the detailed map (Fig. 3), the general regional structure is complicated by small domes or anticlines and basins or synclines. The irregularity in shape and distribution of these structures, their relatively small size and low dips, and their variable alignment, together with the absence of faults, all indicate that some origin other than regional deformation must be appealed to in accounting for them.

On several different occasions, while doing structural work on the coals of southwestern Indiana, the senior writer (Mr. Malott) has found evidence supporting the theory that many of the small irregular domes and basins, or anticlinal and synclinal flexures, were formed as a result of differential compacting or subsidence of the muds which were deposited either on a sea bottom of some topographical diversity or over and about a sand lens which was deposited practically contemporaneously with the overlapping muds.

In either case differential settling and compacting of the muds would bring out in relief the buried hills or sand lenses as anticlines or terraces, which would become less pronounced upward through the overlying formation.[1]

[1]The idea of local domes and basins being formed by the differential compacting of muds over and about a mass which could be compacted but little was proposed long ago in geological literature and has been elaborated and used very frequently since its proposal. Reference will be made here only to a few of the more recent papers, for a detailed review of the literature on this subject is beyond the scope of this paper. See: E. Blackwelder, "The Origin of the Central Kansas Oil Domes," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 4 (1920), pp. 89-94; L. P. Teas, "Differential Compacting the Cause of Certain Claiborne Dips," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), pp. 370-78; H. D. Hedberg, "The Effect of Gravitational Compaction on the Structure of Sedimentary Rocks," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 1035-72; R. W. Brown, "Origin of the Folds of Osage County, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12 (1928), pp. 501-13; and R. W. Brown, "Occurrence of Folds of the Osage Type," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12 (1928), pp. 675-77. In the last paper Brown states (p. 676) that folds of Osage type probably occur in Indiana in the Ditney quadrangle. See also C. M. Nevin and R. E. Sherrill, "Studies in Differential Compaction," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), pp. 1-22.

An example of a dome which probably owes its origin and contour to differential compacting of sediments about and over a buried sand lens has been mapped by Malott approximately 1½ miles northwest of Linton, Greene County, Indiana.

The contours drawn on Coal IV show a nearly round dome with a diameter of about a mile and a closure of more than 40 feet. A test well, drilled on the top of this dome to Coal III, showed a lessening of approximately 16 feet of the normal interval between Coal III and Coal IV. Subsequent drilling for oil showed a thick sandstone below Coal III with no folding below the Mansfield sandstone, the basal formation of the Pennsylvanian of Indiana.

Rawles[1] concludes that

> Most of the domes of this type are not perfectly developed, usually being terraces closed on but three sides. They are often connected by saddles with other domes. A line of these may be found on a line running southeast from Terre Haute, Indiana.

Although no examples have come to the writers' attention in which structures are due to differential compacting of sediments upon and about buried topographical eminences, such structures may very possibly occur in southwestern Indiana. It seems best, therefore, to consider the low domes and shallow basins shown by contours on the lower member of the West Franklin formation as owing their origin to differential compacting or settling of sediments, chiefly muds, over and around large sand lenses below the formation, rather than to any of the other processes previously mentioned, particularly regional deformation.

SUMMARY AND CONCLUSIONS

The West Franklin formation, consisting of a double-bedded limestone of post-Alleghenian age occurring about 300 feet above Coal V, is an important key horizon in the Pennsylvanian of southwestern Indiana. Both its line of outcrop and the strike of its structural contours approximately parallel the eastern boundary of the Eastern Interior coal basin. The formation continues into Illinois on the north, cropping out along Ashmore Creek in Clark County and in the hills southeast of Palestine in Crawford County; and into Kentucky on the south, cropping out in the bank of Ohio River below Uniontown and in Grundy Knob in Union County.

The regional dip of the formation is toward the west at 20-30 feet to the mile. In the southern part of the outcrop area, detailed structural

[1]Unpublished M. A. thesis at Indiana University, 1926. Quoted with the author's permission.

maps show small low domes and shallow basins complicating the uniform regional dip. These minor structures, which are possible reservoirs for oil and gas, are thought to have been formed by differential settling and compacting of muds over and about bodies of sand or sand lenses.

DISCUSSION

GAIL F. MOULTON, Urbana, Illinois: The paper by Robert R. Shrock and Clyde A. Malott contains valuable geologic information on southwestern Indiana, and it is an important contribution to the geology of that region. Their conclusion, however, regarding the origin of the minor structural features in the region should not be applied generally. The casual reader, not familiar with the region, would be led to infer that the authors intend a general application of the conclusion that unequal compacting of sediments of Pennsylvanian age has resulted in the development of local structural "highs" over the thicker sand bodies. Although the detailed structure map includes an area which extends only a moderate distance north of Ohio River, the authors cite the case of a minor structure nearly half way to the northern part of the state in support of their conclusion. Thus a general application of the conclusion seems to be indicated. Some of the Indiana oil pools seem to provide contradictory evidence on this point.

The southwestern Indiana oil pools are unlike most of those in southeastern Illinois in that they are generally of smaller extent and rarely include areas of more than 500 acres. This condition is due both to the small size of the local domes on which the pools occur, and to the irregular character of the producing sand. The structures generally have a closure of 30 feet or less in the producing beds, and most of them have much less than this amount in the surface formations. Consequently, the type of minor structural irregularities shown on the detailed structure map included in the paper by Shrock and Malott is the type with which most of the oil production of the region is associated.

The following list of the producing oil pools of southwestern Indiana is incomplete, but includes all of those on which the writer has sufficient structural data to determine the relation between the structure of the near-surface formations and the oil-producing formations. Of these pools, all except the Tri-County field are indicated by the presence of favorable structure either in the West Franklin formation or in one of the lower coals in the Pennsylvanian system.

Pool	*County*	*Location*
North Alford	Pike	T. 1 N., R. 7 W.
South Alford	Pike	T. 1 N., R. 7 W.
Oatsville	Pike	T. 1 S., R. 9 W.
Francisco	Gibson	T. 2 S., R. 10 W.
Oakland City	Pike	T. 2 S., R. 8 W.
Shell	Gibson	T. 2 S., R. 9 W.
Tri-County	Corner of Gibson-Pike-Warrick Counties	
Siosi	Vigo-Sullivan	T. 9-10, N. R. 10 W.

In most of these pools the structure of the Pennsylvanian is similar to that of the Chester and deeper producing formations, but is not nearly as pro-

nounced. Consequently, it seems to the writer that the only just conclusion to be drawn regarding the origin of the structures, is that, although many of the minor structures in southwestern Indiana are probably caused by unequal compaction of sediments of Pennsylvanian age, fairly complete data for a number of oil pools in the region show that some minor structures in the surface formations indicate the presence of more pronounced structures in the underlying formations. In prospecting for oil on these structures, failure may result from adverse sand conditions in the prospective producing formations; in such cases, the structure should not be condemned.

UNDERGRADUATE PREPARATION FOR THE GEOLOGIST[1]

ELLIS W. SHULER[2]
Dallas, Texas

ABSTRACT

In reorganizing the undergraduate courses given in geology at Southern Methodist University, a study of the catalogue offerings of courses in geology in about one hundred colleges and universities was made. It was attempted to determine what courses in geology should be offered for a geology major for the A. B. degree and as a general foundation and background for specialized graduate training in geology. This study showed a bewildering lack of uniformity in the progressive development of the subject and in the type and character of the courses offered.

As universities have developed larger departments of geology, courses have been diversified and more and more have been pushed into the undergraduate field. In some institutions specialization is begun even in the sophomore year. (The writer here enters a vigorous protest against the attempt to make professional geologists out of undergraduates.)

It is true, perhaps, that some undergraduate work should be specialized, as typed by the locality in which the school is located; nevertheless, it seems that there should be a minimum of standard training in geology, as in other sciences, upon which specialization should be built. Such standard preparation should also meet the prerequisite demands for graduate work in geology for the master's or doctor's degrees, which usually amount to four or five one-year courses.

With the hope that the wide range of geological phenomena met by oil geologists would enable them to throw light upon the quality and quantity of such general preparation in geology, a questionnaire was mailed to one hundred active members of the American Association of Petroleum Geologists. A majority of this group are also members of the Geological Society of America. The writer wishes to thank the more than eighty-five men who were interested enough to answer this questionnaire. General conclusions, only, are recorded in this paper.

[1]Read before the Association at the Fort Worth meeting, March 23, 1929. Manuscript received by the editor, April 22, 1929.

[2]Professor of geology, Southern Methodist University.

Ninety per cent of the geologists believed that it is wise for the freshman to take geology, and the consensus of opinion was that work in geology should be carried throughout each college year rather than concentrated in the senior year. As to the character of the freshman course, more than three to one felt that a general survey course in geology, covering physiographic, structural, dynamic, and historical geology, with the cultural aspect emphasized, should introduce the subject to the student.

As desirable for undergraduate work in geology, the following courses were most frequently chosen (numbers refer to semester-hours): General Geology, 6; Mineralogy, 6; Economic Geology, 3; Structural Geology, 3; Paleontology, 3 or 6; Field Geology, 3 or 6; Stratigraphy-Index Fossils, 3; Sedimentation, 3; Rocks and Rock Minerals, 3; Oil Geology, 3; Advanced General Geology, 3 or 6. This would give a total of 42 semester-hours.

In a school with liberal electives for the A. B. degree, not more than 36 semester-hours are allowed, while the average is probably 30 hours work for the major subject. Yet different courses in geology for undergraduates, totaling more than 174 semester-hours, are listed by American colleges and universities!

While a majority of the replies indicated the general introductory course in geology, including historical geology, as desirable for freshmen, the proper sequence of courses as tabulated for sophomore, junior, and senior years was disappointingly inconclusive. The following courses were suggested for the sophomore year (numbers refer to semester-hours): Mineralogy, 6; Rocks and Rock Minerals, 3; Economic Geology—non-metals, 3; Oil Geology, 3; and Historical Geology, 3 or 6, by those geologists who did not think freshmen eligible for this subject. The course in mineralogy was chosen by the majority, but many chose a sophomore year of two 3-hour courses from the preceding list, such as economic and oil geology, or rocks and rock minerals and economic geology.

No sequence was found for the junior and senior years. The vital importance of training in field geology and the desirability for an advanced course in general geology to be given with a slight preference for the senior year was evident. As was to be expected from the group questioned, courses in stratigraphy or index fossils and sedimentation were found in numerous lists. Several, however, expressed the opinion that "Oil Geology" should be left for graduate work.

Some interesting schedules submitted are as follows:

	1	*2*	*3*	*4*
Freshman	Gen. Geol. 6	Gen. Geol. 6 Structural 3	Gen. Geol. 6 Rocks, Min. 3	Gen. Geol. 6
Sophomore	Mineralogy 6 Rocks, Min. 3	Rocks, Min. 3 Stratigraphy 3	Paleon. 3 Physiog. 3	Mineralogy 6 Paleon. 6
Junior	Structural 3 Econ. Geol. 6	Field Geol. 3 Paleon. 3	Historical 3 Sedimentary 3	Field Geol. 6 Econ. Geol. 6
Senior	Field Geol. 6	Petrol. Eng. 3	Stratigraphy 3	Petrography 3

Very definite opinions were expressed as to correlated and general studies. Physics, mathematics, chemistry, botany, biology, zoölogy, mechanical drawing, sketching, business management, surveying, and astronomy were repeatedly suggested as desirable studies for the would-be geologists. German and French were most frequently suggested for foreign language preparation, though Spanish had many advocates.

One of the most interesting replies of the questionnaire was the repeated urge for extensive training in English composition. Heads of geological staffs wrote feelingly about this feature.

The repeated urge that students who expect to make geology a profession take a wide grouping of courses in chemistry, physics, mathematics, surveying, languages, English, and courses of more general cultural type only re-emphasizes the importance of leaving specialized courses to graduate work in geology.

With the view of checking the results of the questionnaire, a letter was also written to several graduate schools in geology to determine what prerequisite work in geology was required for graduate study. The results of this correspondence, summed briefly, is that four or five one-year courses, 30 semester-hours, are required, but the only definite prerequisites are general and historical geology and mineralogy.

The United States Civil Service examination for Junior Geologists of the United States Geological Survey gives a further check on undergraduate instruction. Competitors are rated on the following subjects:

Subjects	*Weights*
1. General geology	40
2. Translation into English of scientific matter (either French or German)	10

3. Elementary Chemistry, Physics, Algebra, Geometry, and Trigonometry	20
4. Optional subject (at least one of the optional subjects listed below must be taken)	30
Total	100

Optional subjects are: (1)Economic Geology, (2) Groundwater Hydrology, (3)Paleontology, (4) Petrology, (5) Stratigraphy. Applicants must hold a bachelor's degree requiring the completion of at least 118 semester-hours, of which at least 12 semester-hours must have been in geology.

The following comments from the questionnaire on the training for geologists are worthy of record.

I am very much interested in your attempt to work out a satisfactory sequence of courses for students in geology. Our own experience, which covers hundreds of applicants, is that most of these men are deficient in the other sciences. A failure to understand the fundamentals of chemistry makes it impossible for many men to comprehend the basic facts of erosion, besides the more complicated chemical processes involved in the formation and deposition of minerals. Our preference is usually given to men who are well grounded in chemistry, physics, mathematics, and biology, and, above all, who can write English.—E. A. S.

On one point only have I a very definite conviction, that is, that a student during his undergraduate course should not take any applied geology. With the competition that exists in petroleum geology or, in fact, in any branch of applied geology, no student is prepared to make his way with undergraduate training only. Too many young students have been ambitious to become petroleum geologists after having had an elementary course in that subject, without the necessary fundamental training. The colleges and universities of the country have encouraged this by offering courses of a practical nature to students who are not prepared to take them.—O. B. H.

Geologists are born and not made. All students not particularly fitted for the profession both mentally and physically should be discouraged. They should be in love with the profession as a science and not as a meal ticket.

Geology is probably the "broadest" subject that a student can take, as it covers the whole earth, and it is practically necessary for the student in geology to specialize in that part of geology which he will use later in life.—A. L. W.

Do not believe that such specialities as "oil geology," "sedimentation," "soil geology," et cetera, have any place in the undergraduate curriculum.—R. K. M.

I was talking of the teaching of geology with Dr. H. E. Gregory, head of the department at Yale, one time when he said he did not know what to teach the undergraduates. He said something like this: "We let them study the fundamentals and throw them out to get their specialized training in the field and I think they do as well as any other."—G. H. N.

The modern geologist should be an engineer as well as a geologist. I would suggest that such engineering subjects as mechanics, testing of materials,

strength of materials, general surveying, mapping, et cetera, should be included in general courses of geology.—W. C. E.

The hardest of all tasks is to make students think and reason for themselves and not to be imitators like parrots or monkeys. Facts are very much less important than principles and the greatest handicap of the student is his disposition to accept what he is taught as law and gospel. Nothing is more important to inculcate than the habit of being critical and finding out things definitely for one's self.—C. L. B.

For many years I have been employing men from the various colleges and universities throughout the United States and I find that the fundamental attitude of these men toward their work and toward the companies which employ them differs in different schools. I have stated that a geologist should have a thorough college course, not too much specialized in the undergraduate work, but I should like to say also that a great deal of his success depends on the interest which he shows in his work and the spirit of loyalty which he gives to the organization with which he is later associated. I am more and more impressed with the influence on character exercised by the professors in the various universities.—C. H. W.

UNCONFORMITIES IN UPPER CRETACEOUS SERIES OF TEXAS[1]

LLOYD W. STEPHENSON[2]
Washington, D. C.

ABSTRACT

The Upper Cretaceous or Gulf series of Texas is separated from the Comanche series below, and from the Eocene series above, by pronounced unconformities. Unconformities within the series have not heretofore been generally recognized, although several of them have been indicated in previous publications. These stratigraphic breaks are recognized in part by physical features at the contacts, and in part by the absence of lithologic members and paleontologic zones which would be expected to be present in the sections had there been no emergence and erosion. The stratigraphic relations of the formations composing the series in central Texas are shown in a generalized chart. Descriptions and illustrations are given of an ideal typical Coastal Plain unconformity, and of several specific localities at which unconformities have been observed within the series. These unconformities, and numerous minor interruptions to sedimentation (diastems), record differential warping off the flanks of, and between, the Llano-Burnet and Ouachita uplifts, and resultant transgressions and regressions of the sea.

The Upper Cretaceous or Gulf series of Texas is separated from the Comanche series below by an unconformity which certainly represents a considerable interval of geologic time. The Gulf series is separated from the Eocene series above by an unconformity of truly major time importance. Between these larger sedimentary breaks the Gulf series, aggregating more than 3,000 feet in thickness where most fully developed, is composed largely of fine sediments—clays, marls, chalks, and fine sands—which were deposited in marine waters with only a subordinate development of coarse sands and gravels. In fact, the Woodbine, the basal formation of the series, is the only conspicuous exception to the prevailing fineness of the sediments which make up the series. The Woodbine is composed chiefly of medium to coarse sand, with some gravel, and with important members of non-calcareous clay. Even this coarser formation originated mainly in shallow marine water.

Because of the fineness of its sediments, and the approximate parallelism of the bedding planes, the Gulf series has been generally regarded

[1]Read before the Association at the Fort Worth meeting, March 23, 1929. Manuscript received by the editor, May 18, 1929. Published by permission of the director, U. S. Geological Survey.

[2]Chief of Section of Coastal Plain Investigations, U. S Geological Survey.

as conformable throughout, and only within the past few years have unconformities (or disconformities) been recognized within the series, and by no means all of these stratigraphic breaks have as yet been discovered. The facts here presented show that the predominance of fine marine sediments and the absence of conspicuous basal conglomerates and sandstones can not be taken as conclusive evidence that there are no stratigraphic breaks within the series.

The stratigraphic breaks within the Upper Cretaceous series were caused by crustal warping in proximity to the coast-line belt of Upper Cretaceous time, which resulted in retreats and readvancements of the strand line over this belt. During the periods of submergence marine sediments were laid down on the sea bottom, and during the periods of emergence the sediments previously deposited were subjected to erosion and were partly removed and transported to the sea. During any given period of emergence, not only were no sediments laid down to represent that period, but the sediments deposited during the pre-erosion period were in part removed. The sediments of a succeeding period of submergence were therefore laid down upon an erosion surface, and the contact separating the freshly deposited sediments from the older underlying beds marks a period of geologic time of longer or shorter duration, which is not represented by sediments in that area. Because the lands adjacent to the coasts of Upper Cretaceous time were low-lying, the streams were unable to transport coarse sediments to the sea from the distant uplands; therefore, coarse sands and gravels were not laid down above the contacts.

The time represented by any given unconformity is determined by the length of the period of emergence plus the time represented by the strata removed by erosion. The time value of the unconformity is normally greatest along the line of its outcrop, decreases down the dip under cover in the seaward direction, and reaches its least value along the line marking the greatest retreat of the sea whose withdrawal was responsible for the unconformity. At this line that part of the stratigraphic break to which the term unconformity is usually applied, ends, but the break itself does not end at this line, for there is always an off-shore shallow-water belt of greater or less width parallel with a strand line, in which waves and currents prevent the deposition of any except a meager amount of the coarsest sediments. In this belt, therefore, where there was no subaerial erosion, and in which the deposition of fine sediments was prevented by shallow-water conditions, there is a minor stratigraphic break of the kind to which Barrell applied the term diastem. The time value

of a diastem is ordinarily small, but it is greatest along the shore line and decreases off shore, becoming nil where the water becomes deep enough to permit uninterrupted sedimentation. Diastems may of course be formed wherever the sea becomes so shallow that the accumulation of sediments is prevented by waves and currents. Most Coastal Plain unconformities pass coastward into diastems.

A typical coastal plain unconformity is shown diagrammatically in Figure 1.

Several kinds of criteria that may be useful in the recognition of sedimentary breaks within a series of fine marine sediments, are as follows:

1. A thin conglomerate composed of pebbles, bones, teeth, and other hard objects, mechanically re-worked in the base of an overlying formation.

2. A thin layer of phosphatic nodules and phosphatic fossil casts of organisms. This layer generally means a stratigraphic break, but it may be difficult to determine whether it marks a diastem, a minor unconformity, or a major unconformity.

3. A phosphatic layer which includes water-worn materials obviously derived from older formations, such as fossil shells, phosphatic fossil casts, bones, shark teeth, pebbles, and rock fragments. This generally marks an unconformity caused by emergence and erosion.

4. Sharp differences in the lithology of the materials below and above the contact between two beds. This alone is not sufficient to prove an unconformity, as such differences may have been caused by an abrupt change in the character of the sedimentation.

5. An uneven or undulating contact which cuts across the bedding planes of the underlying formation. This marks an unconformity caused by emergence and erosion.

6. The presence of distinctive faunal zones immediately below and above a contact, which zones are known to be separated elsewhere by sedimentary beds of greater or less thickness.

7. Discordance in the dip of the beds below and above a contact. In the Coastal Plain differences in dip at unconformable contacts are generally so slight that they can not be detected in small outcrops. Pronounced differences in dip are, however, not unknown.

8. Borings made by marine organisms of the littoral zone, which extend from the contact downward into the underlying beds to depths of 18 inches or more, filled with material like that composing the bed above the contact.

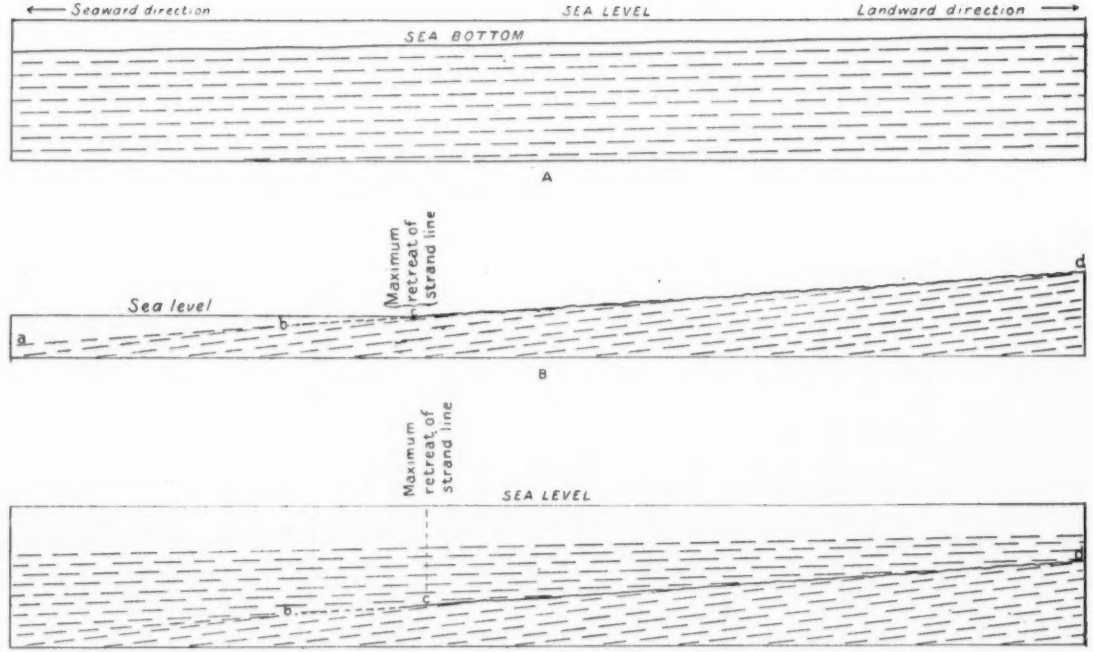


FIG. 1.—Diagrams illustrating formation of a coastal plain unconformity. *A*. A given coastal plain tract is covered by the sea and is receiving sediments over the whole area. *B*. The same area is uplifted, tilted, and part of it emerges from beneath the sea. In the area from *a* to *b* sedimentation continues without interruption; from *b* to *c* sedimentation is prevented by waves and currents; and from *c* to *d* the previously deposited sediments are eroded and partly removed. *C*. The same area is depressed and submerged and sedimentation is resumed over the whole area. The stratigraphic break from *b* to *c* is a diastem and that from *c* to *d* is an unconformity.

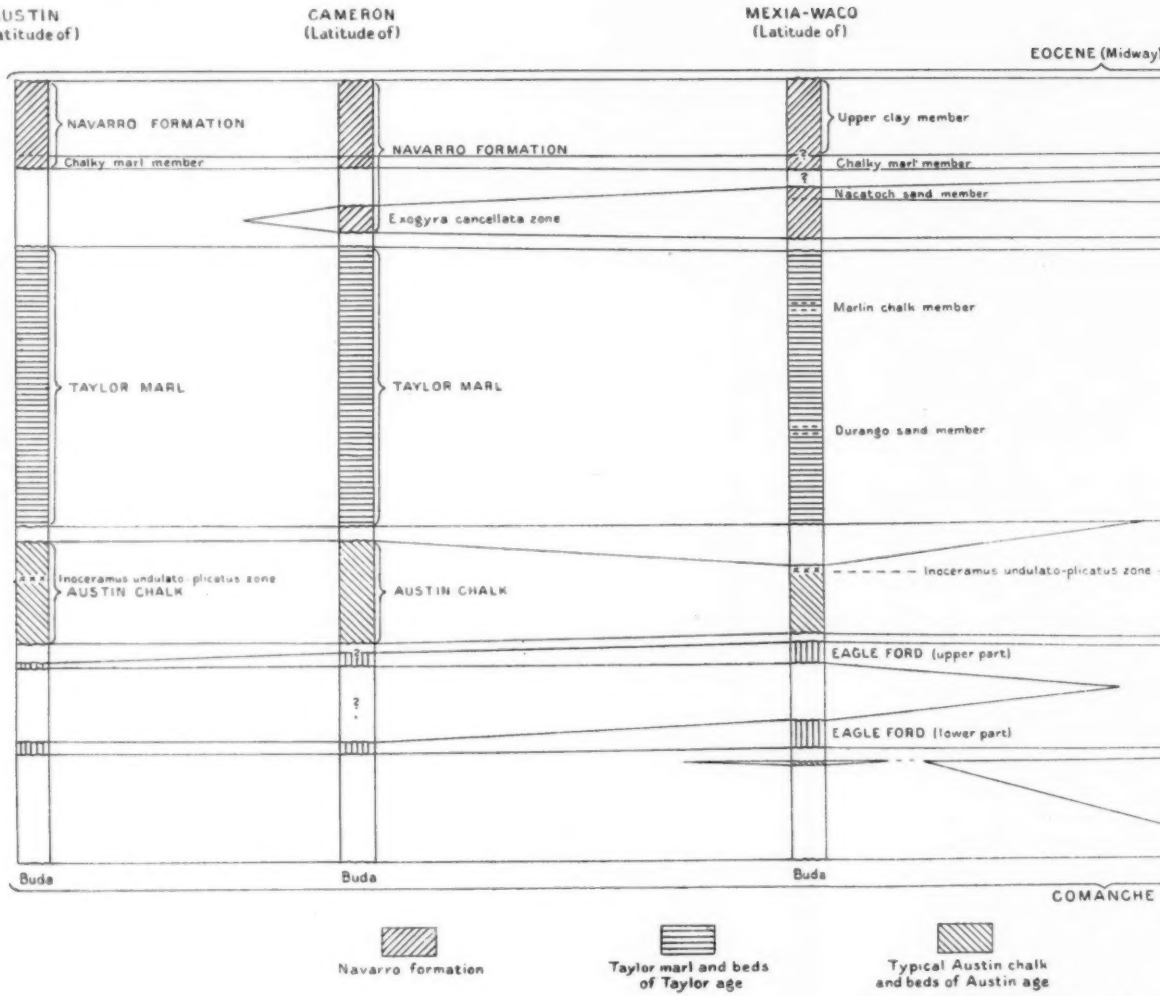
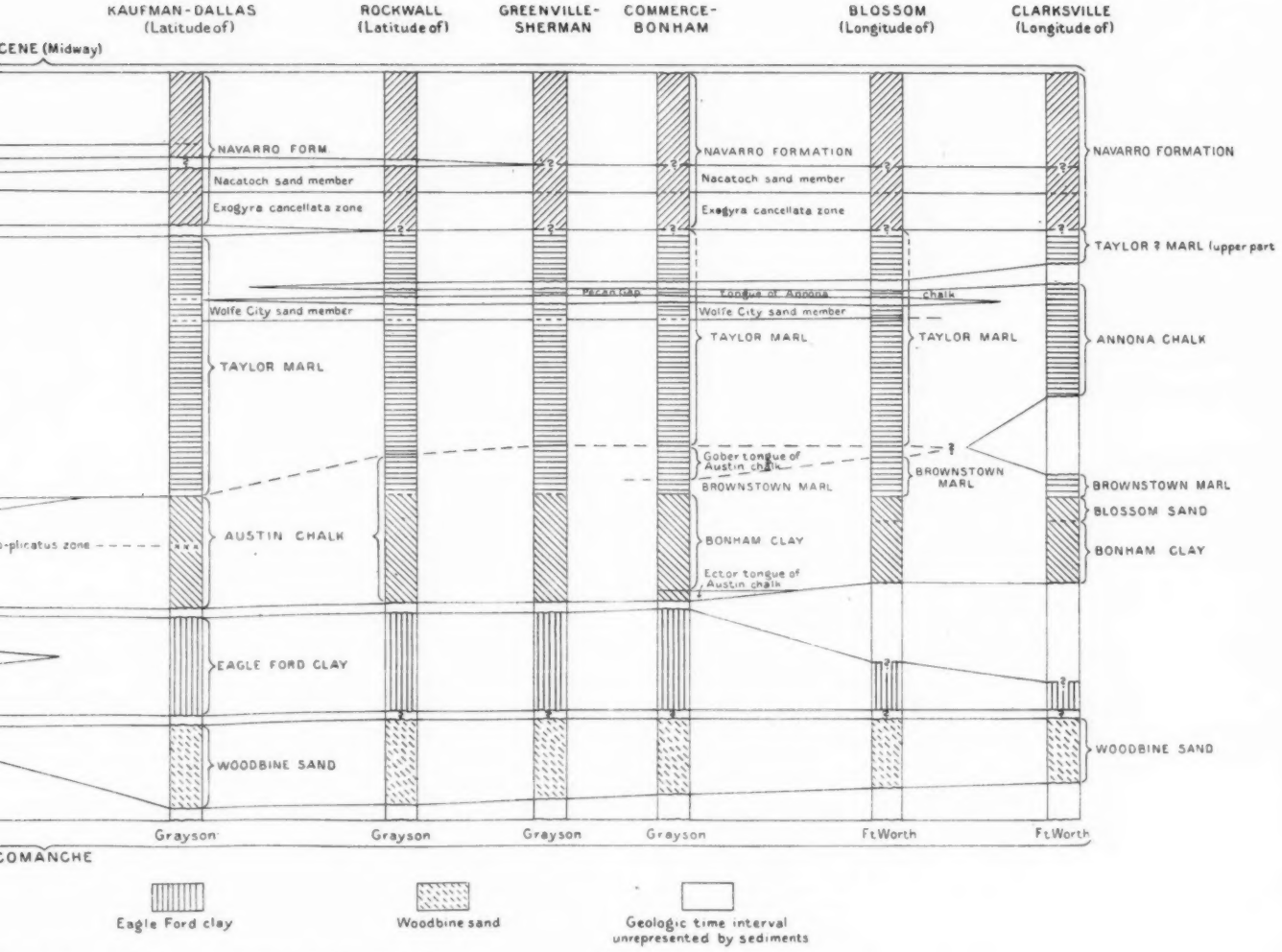


Chart showing the stratigraphic relations



hic relations of the upper cretaceous series of central Texas.

By means of these criteria unconformities have been recognized at the base of, and within the Gulf series, as described in following paragraphs. The recognized unconformities are graphically shown in Plate 13.

The absence of some of the genera, and of all of the species, which occur in the upper part of the Comanche series, from the lower beds of the Gulf series, and the appearance of new species and new genera in the latter, are indicative of a stratigraphic break between the two series, but in addition to this faunal evidence, a sharp change in lithology, from limestone and marl to sand, and an erosion surface observed at the top of the Comanche series at several places, afford evidence of such a break. Hill[1] has described one locality in Denton County, which shows this erosion surface. Another locality where an unconformable contact is revealed at this position is on the Denison-Cedar Mills road, in the west-facing slope of Mineral Creek valley, 1½ miles southeast of Cedar Mills, Grayson County. The lower part of the Woodbine formation consists of irregularly bedded sand, sandstone, and clay, with a thin basal layer of hematitic iron ore concretions, resting upon 2 feet of Grayson marl carrying *Exogyra arietina* Roemer, which in turn overlies Main Street limestone, also carrying *E. arietina*. All but 2 feet of the Grayson marl, which elsewhere in Grayson County has a maximum measured thickness of 25 feet, was eroded away before the Woodbine was laid down upon it. The transgression of the Woodbine sand over successively lower divisions of the Comanche series, from west to east through the southeastern part of Oklahoma, until in Arkansas the Woodbine rests upon the Trinity formation, affords further indisputable evidence of a stratigraphic break approaching major proportions.

An unconformity between the Woodbine sand and the overlying Eagle Ford clay is indicated, at least from Tarrant County southward, by a sharp lithologic change at most places where the contact has been examined, and by some mechanically re-worked material in the basal bed of the Eagle Ford. At several localities in Johnson and Hill counties water-worn sandstone pebbles as much as 2 inches in their longest dimension, were observed in this basal bed, and in a new road cut a mile northeast of Tarrant Station, Tarrant County, the basal bed of the Eagle Ford beneath beds carrying *Acanthoceras* aff. *A. rotomagense* Defrance consists of a hard conglomerate containing many dark phospahtic pebbles and some fish bone fragments, resting on Woodbine sandstone.

[1]Robert T. Hill, "Further Contributions to the Knowledge of the Cretaceous of Texas and Northern Mexico," *Bull. Geol. Soc. Amer.*, Vol. 34 (1923), No. 1, p. 72.

In Grayson and Denton counties in northeastern Texas the physical evidence of this break is not so clear as it is farther south.

The Eagle Ford clay in Dallas County is more than 400 feet thick, but from Hill County southward the formation becomes thinner until at Austin in Travis County it is only 30 feet thick. Evidence, chiefly faunal, has been accumulating, that this thinning is due, in part at least, to a stratigraphic break within the formation. In McLennan County (latitude of Waco) where the Eagle Ford is about 120 feet thick, both the upper and lower parts of the formation are present as shown by the ammonites, but seemingly an intermediate part of the section is wanting. A similar break occurs in Travis County where the thickness of the formation is only 30 feet. On Bouldin Creek, 1¾ miles south-southwest of the Capitol at Austin,[1] the bentonitic zone of the lower Eagle Ford is present, and yields the genus *Exogyra columbella* Meek, which in Texas is not known to range above the lower Eagle Ford, and poorly preserved ammonites which suggest the *Acanthoceras*, or basal, zone of the formation farther north. The upper 2 feet of the section yields *Coilopoceras*, *Prionotropis*, and *Prionocyclus*, which are upper Eagle Ford fossils, and intermediate beds, including the lower part of the *Prionotropis* zone and the *Metoicoceras whitei* zone, are wanting. A phosphatic zone at the base of the upper 2 feet of the section is believed to mark this stratigraphic break.

Evidence of an unconformity between the Eagle Ford clay and the overlying Austin chalk is afforded by a phosphatic conglomerate of varying thickness up to a maximum of perhaps 12 inches, which has been traced from northeastern Texas, where Taff[2] called it the "fish-bed conglomerate," southward to Hays County, and it may extend much farther. This conglomerate contains fossil material re-worked from the underlying Eagle Ford, including several kinds of oyster shells and the teeth of several kinds of fish. In Travis (latitude of Austin) and Hays counties borings extend from the base of the Austin chalk downward into the Eagle Ford clay to a depth of as much as 18 inches, and these are filled with glauconitic chalk exactly like the basal chalk layer of the Austin. Figure 2 shows one of these localities on Blanco River near Kyle, Hays County.

In McLennan County (latitude of Waco), the Austin chalk is unconformably overlain by the Taylor marl, and the contact between the

[1]This section was studied in collaboration with T. W. Stanton and J. B. Reeside, who are in accord with the interpretation here given.

[2]J. A. Taff, *Texas Geol. Survey 4th Ann. Rept. for 1892* (1893), pp. 299-304.

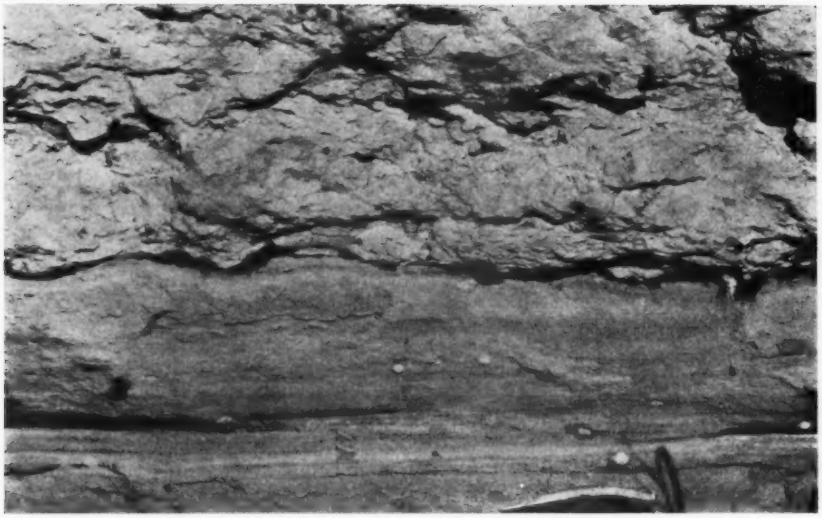


FIG. 2—Eagle Ford-Austin contact, on Blanco River, 2 miles southwest of Kyle, Hays County. The contact lies midway of the height of the picture; the white spots below are borings in the clay filled with glauconitic chalk from above. Scale: 1 inch = 7 or 8 inches.

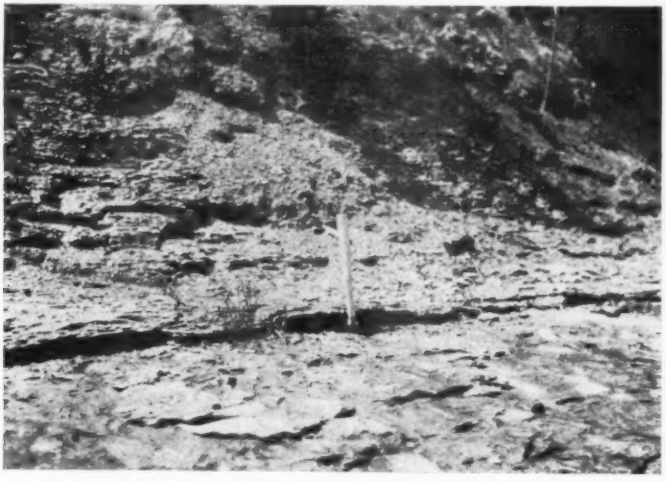


FIG. 3—Austin-Taylor contact on Bullhide Creek, 2½ miles northeast of Lorena, McLennan County. The dark band marks the position of a thin phosphatic conglomerate at the base of the marl. Photo by Willis P. Popenoe.

two formations is marked by a thin but persistent phosphatic conglomerate at the base of the Taylor. The contact is exposed at several places, but the relations are best seen on Bullhide Creek, 2½ miles northeast of Lorena (Fig. 3). At the base of the Taylor is a conglomeratic layer 1-4 inches thick, composed of great numbers of irregular phosphatic nodules, phosphatic casts of mollusks, and shells of a broad variety of *Gryphaea aucella* Roemer. This conglomerate rests with a sharp contact on a hard, massive bed of Austin chalk, in which the shells of the varietal form of *Gryphaea aucella* occur in place. A short distance downstream a layer of chalk 10 or 15 feet stratigraphically lower than the *Gryphaea*-bearing layer contains *Inoceramus undulato-plicatus* Roemer. At the locality near Bynum, Hill County, shown in Figure 4, the contact at the base of the Taylor cuts across the bedding planes of the underlying Austin chalk.

The phosphatic conglomerate at the base of the Taylor has been traced northward through McLennan County, and through Ellis County, nearly to the Ellis-Dallas County line, where it seemingly dies out, and in Dallas County the Austin chalk seems to grade upward without interruption into the Taylor marl. A most significant fact in this connection is the occurrence, in the northeastern outskirts of Dallas, of a layer containing many shells of *Gryphaea aucella* Roemer (a broad variety), and at Whiterock dam, 15 or 20 feet lower in the section, of a layer containing numerous specimens of *Inoceramus undulato-plicatus*. These layers correspond with the layers which, in McLennan County, lie at the top of the Austin chalk. Here they are at least 250 feet below the top of the Austin. The same two fossil zones occur in Travis County (6 miles northeast of Austin) well down within the body of the Austin chalk. These facts seem to show clearly that in McLennan County the Austin and Taylor are separated by an unconformity which elsewhere represents a thickness of as much as 250 feet of strata above the *Gryphaea*-bearing layer.

The Pecan Gap tongue of the Annona chalk in northeastern Texas is separated both from the Wolfe City sand member of the Taylor marl below and from typical Taylor marl above, by unconformities, marked everywhere by phosphatic nodules and casts of fossils. A small exposure in the ditch of an east-west road, 2.6 miles east-southeast of Kingston, 2 miles west of Jacob's store, Hunt County, reveals the lower of the two contacts. The base of the chalk is highly phosphatic, including many phosphatic casts of fossils. The chalk is underlain by greenish-gray marine sand, downward into which many borings filled with chalk extend

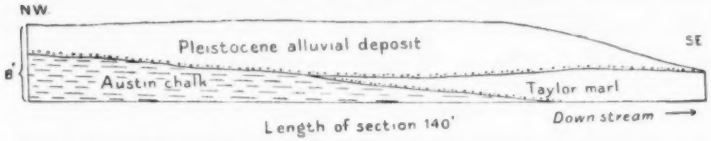


FIG. 4.—Section on left bank of branch 2¼ miles east-southeast of Bynum, Hill County, Texas, showing unconformable contact between Austin chalk and Taylor marl.

to a depth of 2 feet; this is probably indicative of an unconformity. An unmistakeable unconformity at the base of the Pecan Gap is shown by an outcrop on Bear Creek, ½ mile south of the railroad station at Lavon, Collin County, where the base of the chalk cuts down across the eroded edges of clay beds of Taylor age below, as shown in Figure 5. There is a suggestion that the Pecan Gap chalk may have transgressed entirely across the Wolfe City sand onto typical Taylor clay, at this locality, although the clay may be a bed or lens intercalated within the sand. At a locality 3¾ miles southwest of Clarksville, Red River County, the phosphatic layer at the base of the marl of upper Taylor age, immediately overlying the Pecan Gap chalk, contains a few smoothly water-worn quartz pebbles.

In Navarro and Limestone counties (latitude of Waco) the Navarro formation is divisible into at least four parts which from below upward are: (1) the lower Navarro or *Exogyra cancellata* zone; (2) the Nacatoch sand member; (3) an unnamed chalky marl member; and (4) an unnamed upper clay member. The upper clay member and the chalky marl member have been traced southward to and beyond Travis County, but in Travis County (latitude of Austin) the chalky marl rests directly upon the Taylor marl, and the two lower members of the Navarro, the *Exogyra cancellata* zone and the Nacatoch sand, are absent. A section which reveals this contact is well exposed in gullies ¼ mile west of the village of Kimbro. Here non-chalky marl containing a varietal form of

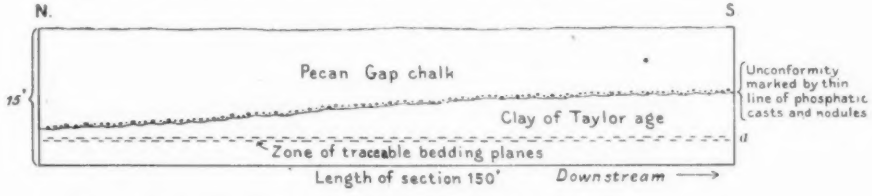


FIG. 5.—Unconformable contact between Pecan Gap chalk tongue of Annona chalk and underlying clay of Taylor age, on Bear Creek, ½ mile south of Lavon, Collin County; *a*, traceable bedding planes in the clay.

Exogyra ponderosa Roemer, which is characteristic of the uppermost part of the Taylor marl, is immediately overlain by chalky marl carrying a micro- and macro-fauna such as is characteristic of the chalky marl above the Nacatoch sand in Navarro and Limestone counties. The contact between the Taylor marl and the chalky marl is sharp, but aside from a few small, dark, phosphatic nodules in the base of the chalky marl, there is nothing in its physical appearance to suggest that it is an important unconformity representing both the lower Navarro and the Nacatoch sand.

In a roadside exposure 8 miles west of Cameron, Milam County, the chalky marl member of the Navarro was observed resting with a sharp, somewhat irregular contact upon the lower Navarro with its characteristic fossil, *Exogyra cancellata*, and the Nacatoch sand was absent.

The stratigraphic break between the Taylor marl and the upper Navarro, which in Travis County accounts for the absence of the *Exogyra cancellata* zone and the Nacatoch sand member, continues toward the southwest with as great or greater magnitude, nearly to the Rio Grande valley where, in the vicinity of Eagle Pass, Maverick County, the gap is only partly filled by the Olmos, a coal-bearing formation. How far this unconformity extends into Mexico has not been determined.

The story told by these unconformities is interesting, although in view of what is already known about the origin and development of sedimentary rocks, it is not a particularly exceptional or remarkable story. The earth's crust is not fixed and immovable, but from time to time is flexed upward or downward in response to deep-seated earth forces, and such movements result in the alternate submergence and emergence of parts of the continents. In Texas crustal warping affected the succession of sediments deposited adjacent to the old Upper Cretaceous shore lines. Off the flanks of the Llano-Burnet and the Ouachita uplifts, or positive elements as they are sometimes called, the columnar sections are less complete than they are in the intermediate geosynclinal, or negative area. This is because the erosion intervals were of longer duration adjacent to the positive areas.

The warping of the Gulf Coastal Plain in Upper Cretaceous time, with the accompanying transgressions and regressions of the sea, and the consequent forward, backward, and lateral shifting of marine faunas, is analogous in certain respects to the broader continental warping of Paleozoic time, which produced the ever-changing epi-continental seas, with their accompanying faunal migrations, so ably described by Ulrich, Schuchert, Butts, and other students of Paleozoic stratigraphy. But

there is this difference. The crustal movements of the Paleozoic admitted first the waters of one ocean, then of another, depending upon the place and magnitude of the warping. The successive sediments of the epi-continental seas may therefore contain strikingly different fossil faunas, depending upon their source, whether in the Atlantic, the Pacific, or the Arctic Ocean. In contrast to the epi-continental seas the fossil faunas of the Upper Cretaceous sediments of Texas all had their source in the same ocean, the Atlantic. They therefore do not exhibit such striking differences as do the faunas of the epi-continental seas, although they do show progressive changes from the older to the younger formations, and also facies differences, that is, differences due to environmental variations from place to place on the ocean bottom. Some of these facies differences are indeed striking. In passing from the lower to the higher beds of the series, some species are known to range through 2,000 feet or more of strata, here and there genera and species drop out of the section, and new genera and species appear in it. But there are no such radical changes in faunal assemblages as would be caused by the flooding with Arctic waters, of an area which had previously been covered by the waters of a tropical or subtropical sea.

Because of the gradual change in the make-up of the faunal assemblages contained in the Upper Cretaceous sediments of the Atlantic and Gulf Coastal Plain, from the lower to the higher parts of the series, the great differences between the faunal assemblages of the uppermost beds of the series and those of the overlying Midway group of the lower Eocene are striking and significant. These differences involve the disappearance of twenty or more genera of mollusks at the end of the Upper Cretaceous, the appearance of new genera in the Midway, and an almost complete change in the specific make-up of the faunal assemblages of the Midway. Although other factors, such as climatic change, and ocean barriers, may have played some part in the production of these faunal differences, it seems necessary to postulate the factor of time—a long interval of time, unrepresented by sediments—to account for them. A prolonged retreat of the sea from the Coastal Plain, and perhaps from the entire continental shelf, would provide the conditions that would satisfactorily explain the absence of sediments containing intermediate faunas between those of the Upper Cretaceous and lower Eocene.

In Denmark there is, between the Maestrichtian, the uppermost undisputed Cretaceous division, and the Montian, the lowermost undisputed Eocene division, an intermediate division known as the Danian. By some paleontologists the Danian is placed in the Cretaceous and by

others in the Tertiary. Any attempt to determine the correlative of the Danian in the sediments of the Coastal Plain must necessarily take into consideration, and account for, the great hiatus indicated by the differences between the faunas of the Upper Cretaceous and those of the Midway Eocene. Rumor has it that evidence seems now to point to the Midway as the possible American equivalent of the Danian. Should this prove to be correct, the proponents of the Cretaceous age of the Danian will find great difficulty in explaining away, or minimizing the magnitude of this hiatus, which would then necessarily be within, and not at the top of, the Upper Cretaceous series.

CORRELATION OF THE CLAIBORNE OF EAST TEXAS WITH THE CLAIBORNE OF LOUISIANA[1]

ALVA CHRISTINE ELLISOR[2]
Houston, Texas

ABSTRACT

The history of the Claiborne group of East Texas and Louisiana is given, including definitions of the Claiborne formations. On the basis of micropaleontology and lithology, the Claiborne formations are divided into members which are correlated. A subsurface cross section is given showing the correlation of these members in Louisiana and East Texas. A generalized cross section is given showing the stratigraphic position of these members.

INTRODUCTION

In this paper the writer's purpose is to divide the Claiborne series into members and correlate them. This correlation is based upon field work by the writer and the study of cores from numerous wells in Texas and Louisiana.

For the subsurface section the following wells were selected: Humble Oil and Refining Company's Southern Pine No. 4-A, Houston County, Texas; Humble Oil and Refining Company's Southern Pine No. 3-A, Houston County, Texas; Humble Oil and Refining Company's Southern Pine No. 2-A, Trinity County, Texas; Humble Oil and Refining Company's Southern Pine No. 1-A, Trinity County, Texas; Humble Oil and Refining Company's Bonner No. 1-A, Angelina County, Texas; Simms' Renfro No. 1, Angelina County, Texas; Humble Oil and Refining Company's Temple Lumber Company No. 1-A, Sabine County, Texas; J. B. Greer's Peavy Wilson No. 2, Sabine Parish, Louisiana; Humble Oil and Refining Company's 4 L's No. 1-A, Natchitoches Parish, Louisiana; Humble Oil and Refining Company's Guillot No. 1, Natchitoches Parish, Louisinna; and Palmer Corporation's Crichton No. 1, Webster Parish, Louisiana. (See Figure 1 for location of cross section).

[1]Read before the Society of Economic Paleontologists and Mineralogists at the Fort Worth meeting, March 22, 1929. Manuscript received by the editor, June 4, 1929. Published with permission of the officials of the Humble Oil and Refining Company, Houston, Texas.

[2]Humble Oil and Refining Company.

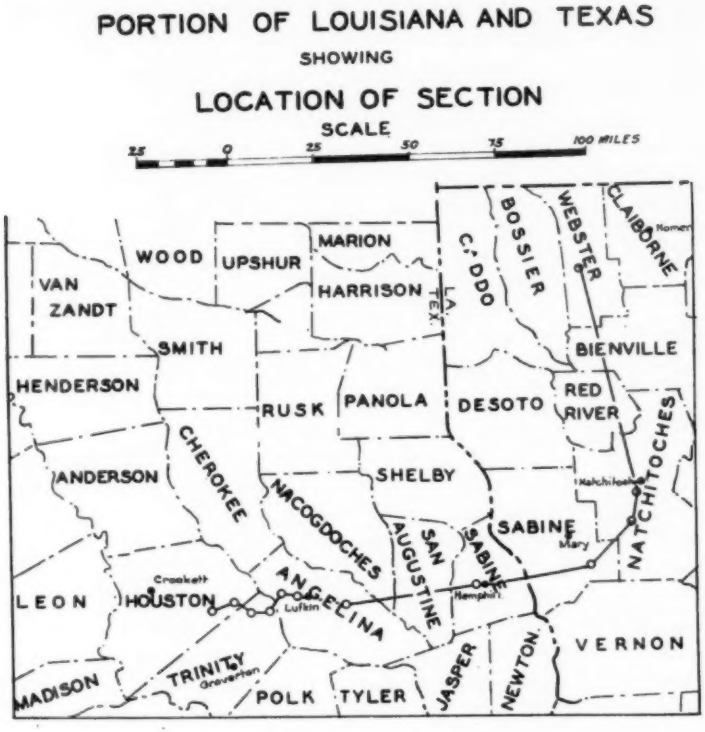


FIG. 1

HISTORY OF CLAIBORNE GROUP

L. C. Johnson,[1] in 1888, was the first to describe sections of the Claiborne formation in Anderson, Henderson, Smith, Cherokee, Rusk, and Harrison counties, Texas. R. A. F. Penrose, Jr.,[2] in 1889, under his series which he described as the Timber Belt or Sabine River beds, gave various sections of the Claiborne. One is as follows:

Two miles west of Crockett, the County Seat of Houston County, is Cook's Mountain, a hill about six hundred yards long, rising gently from the southeast and ending abruptly on the northeast. It is capped by a yellow sandstone con-

[1]L. C. Johnson, "The Iron Regions of Northern Louisiana and Eastern Texas," *House Ex. Doc. 195* (1888), *50th Congress*, Vol. 26 (1888), pp. 19-21.

[2]R. A. F. Penrose, Jr., *Geol. Survey of Texas 1st Ann. Rept. 1889* (1890), p. 34.

taining many shell casts, is cross-bedded and made up of grains of sand, mica and glauconite. Nine miles northeast of Crockett, on the old San Antonio road, is an outcrop of shell-bearing beds similar to that seen one mile south of Elkhart.

Other sections are given of the greensand horizon carrying *Scutella caput-sinensis* and *Ostrea divaricata*. Wm. Kennedy,[1] in 1891, divided the Timber Belt beds into the Lignitic group and Marine beds. The Marine beds he divided into two groups.

The Basal, from its greatest development in Cherokee County, may be called tentatively the "Mount Selman" Series, while the uppermost, from its typical development in Houston County, may be denominated the "Cook's Mountain" Series.

In describing the Cook's Mountain series he said:

They comprise an extensive series of greensands, greensand marls, altered greensand containing thin strata of carbonate of iron; indurated, altered, fossiliferous greensand; green, fossiliferous clays; glauconitic sandstones and clays; stratified black and gray, sandy clays; brown, fossiliferous sands, and black and yellow clays with limy concretions with occasional local deposits of black sand with gypsum crystals. The general section here given represents the beds of this group from Independence Post Office, in Cherokee County, to Alto, a distance of twenty-five miles.

He stated that *Scutella caput-sinensis* and *Ostrea sellaeformis* var. *divaricata* characterize these beds.

This bed occurs at the two places, Alto and Cook's Mountain, and at many intermediate points between.

Kennedy's Cook's Mountain series include the Crockett member and Weches member as described in this paper.

In his definition of the Mount Selman series Kennedy gave a general section from Jacksonville to Bullard, across the Mount Selman beds. The basal part of the Weches as defined in this paper occurs at Jacksonville and at several places in this section

E. T. Dumble,[2] in 1892, defined the Yegua division thus:

To this division is referred the lower portion of the deposits heretofore classed as Fayette beds. Following the Cook's Mountain beds, there comes a series of deposits made up chiefly of sands, sandy clays, clays, and brown coals.

He placed the vicinities of Crockett, Texas and Alabama Bluff on Trinity

[1]Wm. Kennedy "A Section from Terrell, Kaufman County, to Sabine Pass on the Gulf of Mexico," *Geol. Survey of Texas 3d Ann. Rept.* (1891).

[2]E. T. Dumble, "Geology of the Brown Coal Deposits of Texas," *Geol. Survey of Texas* (1892).

River in this group. In 1918 Dumble[1] published his type sections of the Yegua on Elm Creek in Lee County. These sections include the Cockfield member and the Crockett member as defined in this paper. In 1924 Dumble[2] made four divisions of the Claiborne: Yegua, Nacogdoches, Cook Mountain, and Mount Selman.

In Louisiana, L. C. Johnson,[3] in 1888, described various sections of the Claiborne formation, including the section at the mouth of Saline Bayou, at St. Maurice, which Harris,[4] in 1910, made the type locality of all the Claiborne series below the Cockfield sands.

Vaughan,[5] in 1896, gave the name Cocksfield Ferry beds to the series of non-marine sand and lignitic, chocolate shales occurring above the St. Maurice beds on Saline Bayou at St. Maurice and below the basal Jackson formation at Montgomery, Louisiana.

Veatch,[6] in 1906, gave the name Cockfield to these same beds. Later geologists correlated the Cockfield with the Yegua formation of Texas. In 1924, Dumble called all Claiborne beds above the Sparta (Nacogdoches) the Yegua. According to his definition the Yegua division in Lee County includes the Cockfield and Crockett members as defined in this paper. In Louisiana and in Sabine County, Texas, Dumble's Yegua includes the Cockfield, Saline Bayou, Milams, and Crockett members as described in this paper.

The Sparta sands of Louisiana were defined by T. W. Vaughan[7] in 1896. W. C. Spooner[8] in 1926 divided the Claiborne below the Cockfield into St. Maurice, Sparta, and Cane River. He restricted the name St. Maurice to the upper part of Harris's St. Maurice and gave the name Cane River to all beds below the Sparta sands and above the Wilcox formation. His type locality of the Cane River series on Cane River at Natchitoches was listed by L. C. Johnson[9] as early as 1888. On the basis

[1] *Idem*, "The Geology of East Texas," *Univ. of Texas Bull. 1869* (1919).

[2] *Idem*, "A Revision of the Texas Tertiary Section with Special Reference to the Oil-Well Geology of the Coast Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 4 (July-August, 1924), pp. 424-44.

[3] L. C. Johnson, *op cit.*

[4] G. D. Harris, "Lower Tertiary of Louisiana," *Science*, New Series, Vol. 31 (1910), p. 502.

[5] T. W. Vaughan, "A Brief Contribution to the Geology and Paleontology of Northwestern Louisiana," *U. S. Geol. Survey Bull. 142* (1895).

[6] A. C. Veatch, "A Report on the Underground Waters of Louisiana," *Geol. Survey of Louisiana Rept. of 1905.*

[7] T. W. Vaughan, *op. cit.*

[8] W. C. Spooner, "Interior Salt Domes of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 3 (March, 1926), p. 235.

[9] L. C. Johnson, *op. cit.*

of micropaleontology and lithology Spooner's St. Maurice formation can be divided into three members: Saline Bayou, Milams, and Crockett. His Cane River can be divided into Weches, Reklaw, and Cane River. The name Cane River is being restricted in this paper to the glauconitic marls at his type locality on Cane River, ½ mile north of the town of Natchitoches, Louisiana.

DESCRIPTION OF THE CLAIBORNE MEMBERS AS USED IN THIS PAPER

Cockfield.—The Cockfield member consists of a series of massive, light-colored sands alternating with thin-bedded and laminated, sandy, chocolate-colored clays and lignitic clays, ordinarily non-marine. Alexander Deussen[1] gives a locality on Sabine River, ¼ mile below Robinson's Ferry, where the Cockfield is marine in character. The stratigraphic position of the Cockfield member is between the Jackson formation and the Saline Bayou member, which is the topmost member of Harris's St. Maurice.

In Texas, west of Angelina County, the Cockfield member overlaps the Saline Bayou and Milams members and rests upon the Crockett member.

Seaward from the outcrop the Cockfield member becomes marine in character.

Saline Bayou.[2]—The name Saline Bayou is proposed for the series of beds that occur at the type locality of the St. Maurice on Saline Bayou, St. Maurice, Louisiana.

L. C. Johnson,[3] in 1888, described this section as follows:

1. Detrital material resembling orange sand and consisting of rather stiff clay with pebbles. 1-3 feet
2. Calcareous gray clay. 10 feet
3. Clay, more tenaceous and calcareous. 15 feet
4. Indurated, glauconitic sand with a ferruginous seam at the base. 10 feet
5. Indurated, glauconitic sand, less sandy and lighter in color than 4. Fossils present. 1½ feet
6. Lignitic sand. 4 feet
7. Glauconitic sand. 1 foot
8. Dark lignitic sand. 4 feet
9. Glauconitic sand. 1 foot
10. Lignitic sand. Few fossils. 4 feet

[1]Alexander Deussen, "Geology and Underground Waters of the Southeastern Part of the Texas Coastal Plain," *U. S. Geol. Survey Water Supply Paper 335* (1914).

[2]Name proposed by the writer and approved by T. W. Stanton of the U. S. Geol. Survey Committee on Geologic Names.

[3]L. C. Johnson, *op. cit.*

The stratigraphic position of the Saline Bayou member is below the Cockfield member and above the Milams member.

Excellent exposures of this member are found in Winn, Natchitoches, and Sabine parishes, Louisiana, and Sabine County, Texas. The upper part of the bluff at Columbus on Sabine River and Dillon Shoals on Sabine River are the lower part of the Saline Bayou member.

Milams.[1]—The name Milams is proposed for that member of the Claiborne occurring below the Saline Bayou member and above the Crockett member. The type locality is in the northeast quarter of Sec. 17, T. 13, R. 3 W., Winn Parish, Louisiana. This locality is ½-¾ mile southwest of Milams on the Arkansas Southern Railway.

The section is as follows:

1. Red clay, weathering orange. 6 feet
2. Gray, plastic, calcareous, fossiliferous, somewhat glauconitic clay with many corals. Weathers to dull orange-red with a few small lime nodules. 6 feet
3. Gray, calcareous, very glauconitic, fossiliferous clay. Weathers orange-red with numerous small calcareous nodules. 10 feet
4. Zone of calcareous, glauconitic concretions with fossil casts. 6 inches
5. Dark yellowish-gray, very glauconitic, plastic, fossiliferous clay. 3 feet
6. Badly weathered, orange-red, very glauconitic, fossiliferous, sandy clay. Many oysters present. Upper 4 feet very ferruginous and indurated. 10 feet

Crockett.[2]—The term Crockett is proposed for that member of the Claiborne formation in Texas which occurs below the Milams member and above the Sparta sand member. At the type locality in the vicinity of Crockett, Houston County, Texas, the Cockfield overlies the Crockett, overlapping the Saline Bayou and the Milams members.

A composite section is here given extending from 1.8 miles north of Crockett on the Palestine road to 2.6 miles southwest of the courthouse on the Midway road:

1. Calcareous, brownish-gray, fossiliferous clay with zone of small, ferruginous concretions. 15 feet
2. Brown, medium fine sand. 2 feet
3. Grayish-brown clay with sand partings. A few ferruginous concretions. 14 feet

[1]Name proposed by the writer and approved by T. W. Stanton of the U. S. Geol. Survey Committee on Geologic Names.

[2]Name proposed by E. A. Wendlandt and G. Moses Knebel, and approved by T. W. Stanton of the U. S. Geol. Survey Committee on Geologic Names. See E. A. Wendlandt and G. Moses Knebel, "Lower Claiborne of East Texas with Special Reference to Mt. Sylvan Dome and Salt Movements," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 10 (October, 1929).

4. Brown clay, much weathered. 30 feet
5. Brown, sandy clay with streaks of laminated clay, much weathered. 30 feet
6. Ferruginous, glauconitic sandstone. 1 foot
7. Gray, sandy clay with streaks of weathered, glauconitic sandstone. 10 feet
8. Gray, calcareous, fossiliferous clay and chocolate-brown, carbonaceous clay with streaks of light gray sand. 25 feet
9. Ferruginous sand, cross-bedded, and clay lumps. 5 feet
10. Grayish-brown clay with selenite. 30 feet

Those beds in Louisiana which are stratigraphically the same as the Crockett member in Texas have been locally referred to as the Minden beds. The town of Minden is not on the so-called Minden beds but on the Sparta sands.[1] As it is not advisable to use two names for the same member, the name Crockett, which has been used in Texas, is suggested instead of Minden. The outcrops of the Crockett in Texas are better exposures. For these reasons the name Minden is dropped and Crockett used instead.

Sparta.—Below the Crockett member and above the Weches member as defined in this paper, or the Cane River formation as defined by W. C. Spooner,[2] occurs the Sparta sand member. The name Sparta was given in 1896 by T. W. Vaughan.[3]

Spooner[4] describes the Sparta sand as follows:

> The lower half of the Sparta is made up chiefly of sand with interbedded members of laminated, sandy clay. The massive sands are made up of quartz grains, somewhat coarser than found in the Wilcox formation. The upper half contains a relatively greater amount of clay than the lower half. Massive sands alternate with beds of finely-laminated, sandy clay, in part lignitic and in many places containing fossil leaves. The upper fifty feet of beds contain a considerable amount of lignitic material and some thin lignitic beds which are particularly well exposed in the vicinity of the town of Bienville. The beds are commonly light-colored but, depending upon the amount of iron and carbonaceous matter, red and brown beds occur. Fossils are generally absent from the Sparta sand but a few species of near-shore forms are found near the middle of the formation.

Weches.[5]—The name Weches is applied to the massive greensand beds below the Sparta sand member and above the Queen City sand member.

[1]Oral communication from L. P. Teas of the Humble Oil and Refining Company.

[2]W. C. Spooner, *op. cit.*

[3]T. W. Vaughan, *op. cit.*, p. 25.

[4]W. C. Spooner, *op. cit.*, p. 236.

[5]Name proposed by E. A. Wendlandt and G. Moses Knebel and approved by T. W. Stanton.

The following section is exposed on the Crockett road 1.5 miles southwest of Weches in Houston County, Texas:

1. Glauconitic, calcareous, fossiliferous clays, with small, calcareous concretions. 28 feet
2. Very light, fine quartz sand. 5 feet. Clay and sandy clay with ferruginous partings. 5 feet
3. Much weathered greensand, sandy near top. 5 feet
4. Gray to chocolate-gray, glauconitic clay. 4 feet
5. Greensand with fossil casts and streaks of clay, ironstone concretions at top. 4 feet
6. Glauconitic, gray shale with sand streaks and fossil casts. 7 feet

A good exposure of the fossiliferous zone is on the east side of San Pedro Creek on the road southeast of Augusta, Houston County, Texas.

Ostrea sellaeformis and *Scutella caput-sinensis* characterize this member in some areas, particularly near San Augustine, Texas, which name formerly was applied to this member but dropped because of priority.

Queen City.—The Queen City beds were first described by Wm. Kennedy.[1] The Queen City member consists of light gray, fine-textured, micaceous sands alternating with light chocolate-colored, carbonaceous, micaceous, sandy shales. The sands are laminated or thinly stratified, massive, cross-bedded, and in many places interlaminated with clay. Its stratigraphic position is below the Weches member and above the Reklaw member.

Reklaw.[2]—Below the Queen City member and above the Carrizo sands in Texas and above the Cane River member in Louisiana occurs a series of chocolate-brown, glauconitic shales with glauconitic, concretionary ledges; brown, carbonaceous, micaceous, sandy shales, in places lignitic; and greensands. Lignitic, brown sands occur in the lower part.

For this series the name Reklaw is proposed from the town Reklaw in Cherokee County, Texas. One mile east of Reklaw on the Texas and New Orleans Railroad the following section occurs:

1. Glauconitic zone. 5 feet
2. Hard, glauconitic ledge. 1 foot
3. Glauconite with small, irregular shaped concretions. 3 feet
4. Irregular, glauconitic zone. 1½ feet
5. Brown, glauconitic sand. 2 feet
6. Glauconitic, purplish, sandy, harder ledge. 1 foot
7. Brown sand, medium fine, becoming glauconitic at top. 3 feet
8. Gray sand with streaks of gray clay. 2 feet
9. Light brown, medium fine sand. 2 feet

[1]Wm. Kennedy, *Geol. Survey of Texas 3d Ann. Rept.* (1921).

[2]Name proposed by E. A. Wendlandt and G. Moses Knebel, and approved by T. W. Stanton.

A good exposure of fossiliferous Reklaw is found about 5 miles south of Reklaw in Cherokee County. In Louisiana the equivalent clays, the upper chocolate shales of Spooner's Cane River formation, are highly fossiliferous.

In the eastern part of Louisiana and the southern part of the Sabine uplift the Reklaw occurs below the Sparta sands and above the Cane River, as limited in this paper.

Cane River.—The lithology of the Cane River as limited in this paper is a glauconitic, sandy marl and a glauconitic, clayey sand. *Ostrea sellaeformis* var. *lisbonensis* Harris and *Orthophragmina advena* Cushman characterize the Cane River member. The type locality is at Badin Hill on Cane River, ½ mile north of Natchitoches, Louisiana. Excellent exposures of the Cane River member are found within the town of Natchitoches, at Victoria Mills, 2.1 miles north of Provençal; and ½ mile west of Provençal in Natchitoches Parish, Louisiana. The Cane River member occurs stratigraphically above the Wilcox formation and below the Reklaw member in Louisiana.

Carrizo.—The Carrizo sands were originally described by Owen in the first report of the Geological Survey of Texas from the sands at Carrizo Springs, Texas.

E. T. Dumble,[1] in 1911, placed the Carrizo sands in the Claiborne.

E. W. Berry,[2] in 1921, on the basis of paleobotanical studies, placed the Carrizo in the Wilcox.

In Texas, on the west side of the Sabine uplift occurs a fine-textured, clean, white, micaceous sand below the Reklaw member and above the Wilcox formation. On the surface this sand can be traced into the Carrizo sands of Milam County. This sand is lithologically different from the Wilcox and separated from it by an unconformity.[3] For these reasons it is placed in the Claiborne rather than the Wilcox.

A good exposure is found on the south bank of Carey Lake, near Boggy Creek field, in Cherokee County, Texas. It ranges from 10 to 60 feet in thickness.

[1]E. T. Dumble, "The Carrizo Sands," *Texas Geol. Survey Trans.*, Vol. 11 (1911), pp. 52-53.

[2]E. W. Berry, "Additions to the Flora of the Wilcox Group," *U. S. Geol. Survey Prof. Paper 131-A* (1922).

[3]According to oral communication from L. W. MacNaughton, formerly of the Humble Oil and Refining Company, the Carrizo-Wilcox contact showing unconformity is on the west bank of Kilgore-Henderson highway, on north side of first large stream valley about 2½ miles north of Henderson, Rusk County; and on the highway north of Pittsburg, Camp County, Texas, just south of Big Cypress Creek.

SUBSURFACE SECTION

The subsurface section (Fig. 2 and Plate 14) shows how the Claiborne series varies around the Sabine uplift. The correlations were made by means of micropaleontology and lithology.

The section in the Humble Oil and Refining Company's Southern Pine No. 4-A in Houston County is the same as the section occurring on the surface in Houston County and in the basin on the north in Cherokee, Anderson, and Smith counties. From Lufkin west the Cockfield overlaps the Saline Bayou and Milams members and rests directly on the Crockett member. The Crockett member thins toward Sabine River. In the northern part of Louisiana it is correlated with those beds called "Minden." The section occurring in the Humble Oil and Refining Company's Temple Lumber Company No. 1 is the same as the surface section in Sabine County, Texas, where the three members, Saline Bayou, Milams, and Crockett are well defined as three distinct units or members, based on paleontology as well as lithology.

The Sparta sand member is thickest in Louisiana, being as much as 450 feet thick in the Palmer Corporation's Crichton No. 1 in Webster Parish, thinning toward the southern part of the Sabine uplift. It also thins in Texas down dip as shown by the Simms' Renfro No. 1.

In Angelina, Trinity, and Houston counties the average thickness of the Weches is 160 feet. It becomes thinner toward Sabine River, where it disappears on the opposite side of the river, in Louisiana. It also thins toward the north in Cherokee and Smith counties, where it is only 40 feet thick or less. In the northwestern part of Louisiana it occurs in the Palmer Corporation's Crichton No. 1 with a thickness of about 80 feet.

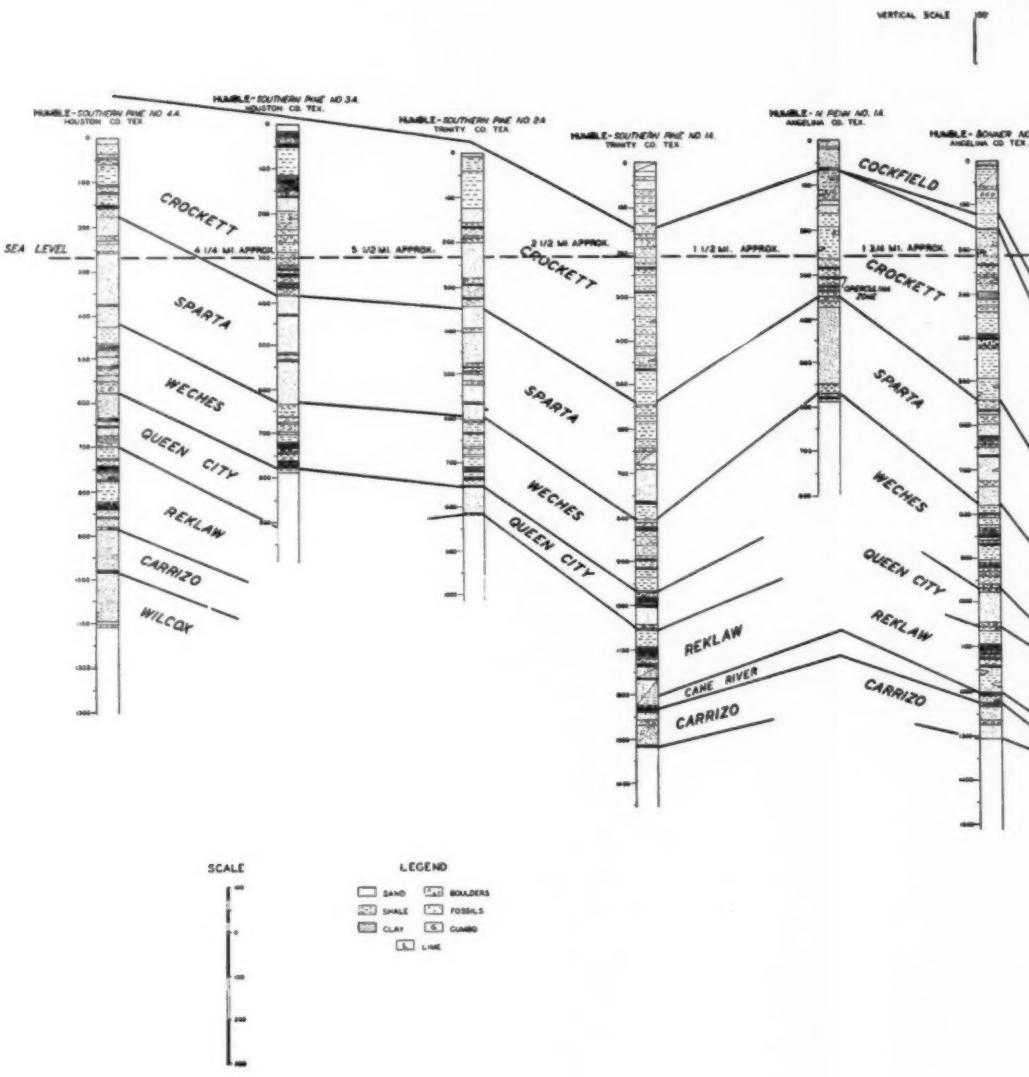
The writer has found the Weches member in wells in Cleveland County and Bradley County, Arkansas. Its occurrence in wells in Louisiana east and southeast of the Sabine uplift has not been observed. Subsurface work proves that the Weches is stratigraphically higher than the Cane River occurring at Natchitoches, Louisiana.

Below the Weches member is found the Queen City sand member, which is limited to the Texas side of the Sabine uplift, according to our present knowledge. As a well defined massive sand the Queen City extends from Queen City in Cass County south through Smith and Cherokee counties, attaining a thickness of 400 feet. In Houston County it thins to 110 and to 90 feet in western Angelina County. From San Augustine east it is only a few feet thick, finally disappearing.

CORRELATION

IN WELLS FROM HOUSTON

BY



SCALE

LEGEND

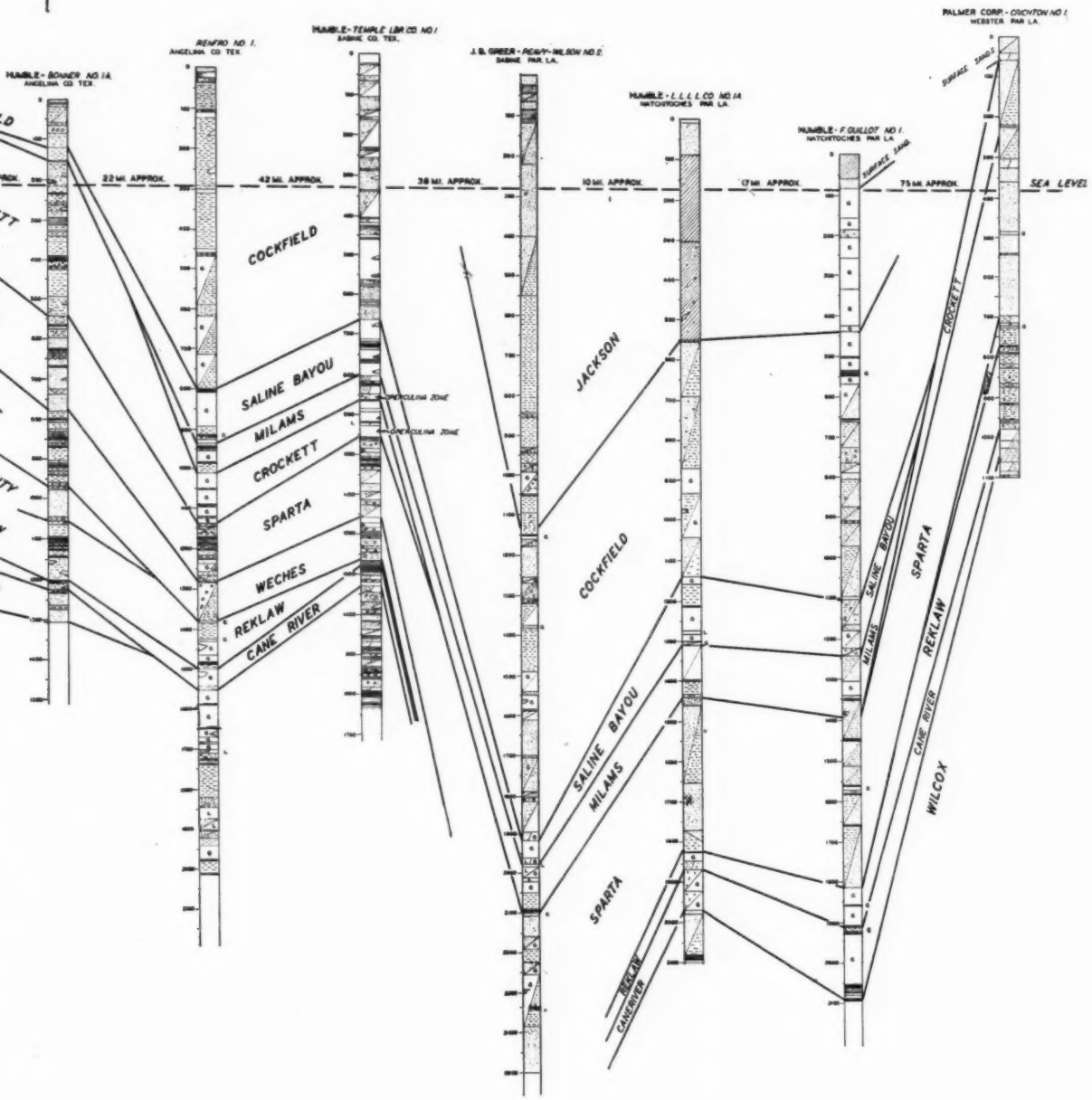
SAND
SHALE
CLAY
BOULDERS
FOSSILS
GUMBO
LIME

ATION OF CLAIBORNE

M HOUSTON CO. TEX. TO WEBSTER PAR. LA.

BY ALVA C. ELLISOR

SCALE 100' HORIZONTAL DISTANCES AS INDICATED


HUMBLE - BONNER NO 1-A ANGELINA CO. TEX.
REMPRO NO 1. ANGELINA CO. TEX.
HUMBLE - TEMPLE LBR CO NO 1 SABINE CO. TEX.
J. B. GREER - ROWY - NELSON NO 2. SABINE PAR. LA.
HUMBLE - L. L. & I. CO NO 14 NATCHITOCHES PAR. LA.
HUMBLE - F GUILLOT NO 1 NATCHITOCHES PAR LA.
PALMER CORP. - CROWTON NO 1 WEBSTER PAR. LA.
SURFACE SANDS
22 MI. APPROX.
42 MI. APPROX.
38 MI. APPROX.
10 MI. APPROX.
17 MI. APPROX.
75 MI. APPROX.
SEA LEVEL
COCKFIELD
SALINE BAYOU
MILAMS
CROCKETT
SPARTA
WECHES
REKLAW
CANE RIVER
JACKSON
WILCOX

DIAGRAMMATIC SECTION

OF THE CLAIBORNE

OF EAST TEXAS AND WESTERN LOUISIANA

BY ALVA C ELLISOR

VERTICAL SCALE 1 inch = 200 feet

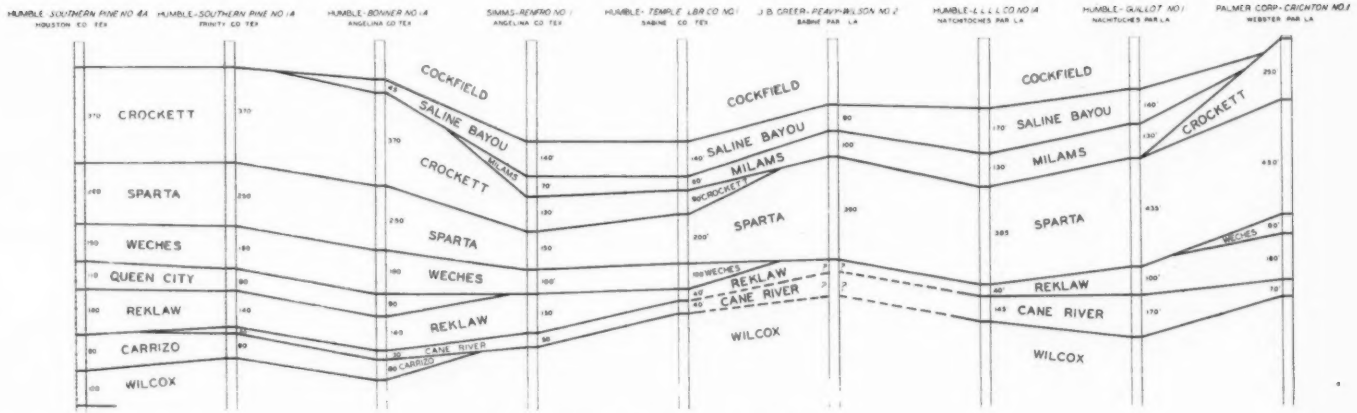

HUMBLE SOUTHERN PINE NO 4A HOUSTON CO TEX
HUMBLE-SOUTHERN PINE NO 1A TRINITY CO TEX
HUMBLE-BONNER NO 1A ANGELINA CO TEX
SIMMS-REMPRO NO 1 ANGELINA CO TEX
HUMBLE-TEMPLE LBR CO NO 1 SABINE CO TEX
J B GREER-PEAVY-WILSON NO 2 SABINE PAR LA
HUMBLE-L L L L CO NO 1A NATCHITOCHES PAR LA
HUMBLE-GULLOT NO 1 NACHITOCHES PAR LA
PALMER CORP-CRICHTON NO 1 WEBSTER PAR LA
COCKFIELD
SALINE BAYOU
CROCKETT
MILAMS
SPARTA
WECHES
QUEEN CITY
REKLAW
CANE RIVER
CARRIZO
WILCOX

FIG. 2.—Scales and thickmesses shown in feet.

The Reklaw member east of the Sabine uplift was deposited in deeper water than north and west of the uplift, where the deposition was in shallow water, as indicated by the meager fauna.

Because of faulting and steep dips the Cane River as limited in this paper does not appear on the surface in Texas with the exception of a few poor exposures of the basal part. The subsurface section shows the Cane River as far west as Trinity County, where the basal part is found in the Southern Pine No. 1-A. The Simms' Renfro No. 1 had 50 or more feet of the marl with a plentiful fauna including the *Orthophragmina advena* Cushman, which is characteristic of the Cane River.

LOWER CLAIBORNE OF EAST TEXAS, WITH SPECIAL REFERENCE TO MOUNT SYLVAN DOME AND SALT MOVEMENTS[1]

E. A. WENDLANDT[2] and G. MOSES KNEBEL[2]
Houston, Texas

ABSTRACT

This paper presents a discussion of the Lower Claiborne of East Texas to show the different divisions of this group, old names of formations being re-defined and such new names being added as have been found necessary to meet present-day thought.

Mount Sylvan salt dome is in the western part of Smith County, Texas. The existence of a dome was verified by the seismograph, and later detail surface work has likewise shown the presence of a dome in this area, although no drilling has been done to date.

The writers discuss the structural features accompanying the formation of this dome, which are believed to be the result of salt movement into the core. Similar conditions have been observed in other domes in the East Texas district. It is probable that the original salt bed is more than 1,000 feet in thickness and 10,000 feet or more below the surface. It is believed that the salt movement originated along points of weakness. This initiating movement, plus isostatic pressure, and the downward push of a settling basin, causes the upward movement of the plastic salt. The domes occur in local synclinal areas in the East Texas geosyncline, and are commonly flanked by well-developed rim synclines. The rim synclines are probably caused by settling, influenced by a thinning of the original salt series by movement into the stock.

ACKNOWLEDGMENTS

The writers wish to acknowledge their indebtendess to Eugene Holman for his encouragement, and to Wallace E. Pratt and L. T. Barrow, of the Humble Oil and Refining Company, for their permission to publish the paper. Dwight Bingham, of the Gulf Production Company, F. E. Poulsen, of The Pure Oil Company, and A. E. Oldham, of the Amerada Petroleum Corporation, have contributed materially by their constructive criticism and help with contacts in certain counties. Sidney Powers has kindly read the paper and offered constructive criticism. Edgar Tobin, of the Edgar Tobin Aero Company, Inc., of San Antonio, Texas, has furnished the aerial map of the Mount Sylvan dome. Sidney A. Judson, of the Humphreys Corporation, has furnished the log of the diamond core drill in Cherokee County, Texas. Lewis W. Mac-

[1]Read before the Association at the Fort Worth meeting, March 22, 1929. Revised manuscript received by the editor, June 24, 1929. Published by permission of the Humble Oil and Refining Company.

[2]Humble Oil and Refining Company.

Naughton, of the Rycade Oil Company, and formerly employed by the Humble Oil and Refining Company, helped with the contacts in Angelina County, and first observed the Omen member of the Queen City in the eastern part of Smith County. Miss Alva C. Ellisor, research paleontologist for the Humble Oil and Refining Company, has assisted in the examination of surface and well samples through a period of years.

Much credit is due the pioneer geologists who did years of work in East Texas. Such men as R. A. F. Penrose, Jr., William Kennedy, E. T. Dumble and associates, Alexander Deussen, and Sidney Powers have paved the way for this work.

INTRODUCTION

This paper consists of three divisions: (1) regional geology, (2) Mount Sylvan dome, and (3) tectonics of salt dome formation. It is presented with the idea of stimulating discussion on the surface geology of East Texas, and to show the different divisions of the Lower Claiborne. Existing names are re-defined and such new names added as have been found necessary to meet present-day thought. The Mount Sylvan salt dome is described in detail in an attempt to show the amount and attitude of movement occurring within the Lower Claiborne beds. The writers discuss the tectonics of salt dome formation.

1. Regional Geology

REGIONAL PHYSIOGRAPHY

The physiographic provinces in which the interior salt domes of East Texas occur are the Wilcox Plain and Nacogdoches Wold.[1] All the domes, with the possible exception of the Grand Saline dome, occur in the Nacogdoches Wold.

The Nacogdoches Wold really begins with the Carrizo formation. Through Leon, Freestone, Anderson, Henderson, Wood, Franklin, Camp, Titus, Morris, Cass, and a part of Van Zandt counties, the cuesta marking the beginning of the Lower Claiborne is indicated by a gentle rise (Fig. 1). There is a decided contrast in topography between the two provinces, that of the Wilcox Plain being almost flat or slightly rolling, and that of the Lower Claiborne generally much more broken and hilly. The section below the Weches greensand produces topography of a low, rolling type contrasted to that formed by the iron ore capping the

[1] A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46* (1906), p. 29.

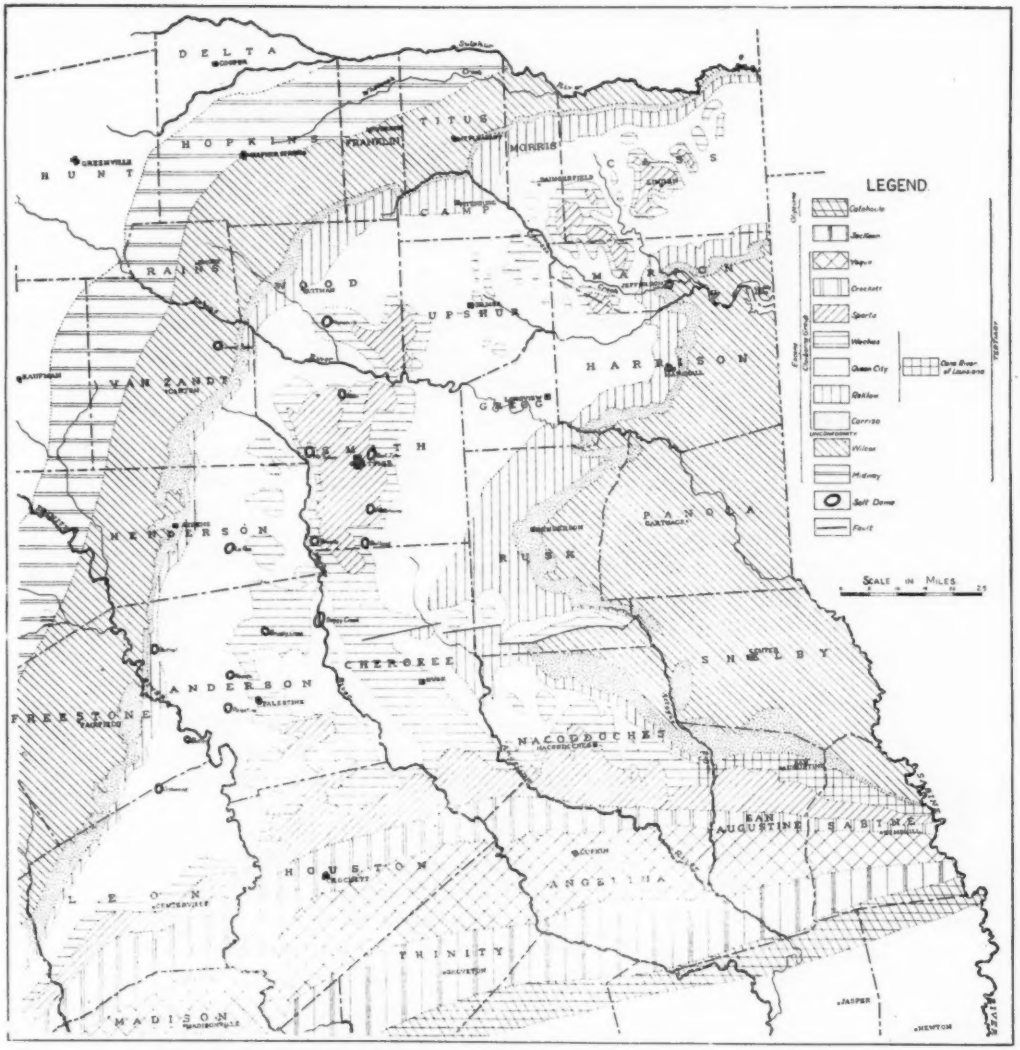


FIG. 1.—Index map of northeast Texas, showing generalized areal geology and location of proved and unproved salt domes. (The Oligocene age of the Catahoula formation is questionable.)

Weches greensand, which gives rise to the outstanding hills and rough topography of East Texas.

REGIONAL STRATIGRAPHY

Only rocks of the Eocene period of the Tertiary are normally exposed in East Texas, and in these are included the formations of the Lower Claiborne group, namely, the Cook Mountain and the Mount Selman formations, with their subdivisions, which are the special subjects of discussion in this paper.

With one exception,[1] practically all of the previous literature on the Lower Claiborne of East Texas is so contradictory that it is thought best to re-define the old names, and apply such new names as were found necessary to fit the constant divisions. Table I gives the old divisions and their correlation with those of the present. The general distribution of these divisions is shown in Figure 1.

WILCOX

That the Wilcox was laid down in a steadily-subsiding basin is indicated by the shallow-water nature of the sediments and the increasing thickness near the center of the East Texas geosyncline. The Wilcox is characterized by its thick beds of lignite, gray lignitic clays, beds of sand, and sandstone concretions. The Wilcox ordinarily gives rise to a moderately level topography and a gray post-oak sandy clay soil. This formation ranges from 800 to 2,300 feet in thickness, according to its position in the geosyncline.

MOUNT SELMAN

Carrizo.—The Carrizo comprises those clear quartz sands and light-colored clays, ranging from 10 to 60 feet in thickness, which lie unconformably upon the Wilcox (Indio) and under the Reklaw glauconitic beds. At several places the unconformity has been noticed, although in other places no such condition could be found. The variation in thickness of the Carrizo, and the irregular conditions found in detailing the Carrizo-Wilcox contact, can best be explained by an unconformity. Around the domes the Wilcox, where exposed, ordinarily shows much more uplift than the Carrizo. The Carrizo, as used here, is the same formation mapped by Alexander Deussen[2] as Carrizo in Milam County, Texas.

[1] B. Coleman Renick, "Recently Discovered Salt Domes in East Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol 12 (1928), pp. 527-542.

[2] Alexander Deussen, quoting "Geology of the Coastal Plain of Texas, West of Brazos River," *U. S. Geol. Survey Prof. Paper 126* (1924), map.

TABLE I

CORRELATION OF TERTIARY FORMATIONS

		Penrose	*Kennedy*	*Kennedy*	*Dumble*	*Deussen*	*Louisiana*	*Present*
TERTIARY	Pliocene			Fleming	Fleming	Lagarto Lapara	Fleming	Fleming — Lagarto
	Miocene					Oakville		Oakville
	Oligocene?	Fayette			Catahoula	Catahoula	Catahoula	Catahoula
	Eocene	Fayette			Jackson — Manning, Caddell, Wellborn	Frio Fayette	Jackson	Jackson
		Claiborne group		Lufkin or Angelina	Yegua	Yegua	Cockfield	Yegua
					Nacogdoches			
		Sabine River	Marine		Cook Mountain	Cook Mountain	St. Maurice Jonesboro Minden Sparta	Cook Mountain — Saline Bayou, Milams, Crockett, Sparta
					Mount Selman	Mount Selman	Cane River	Mount Selman — Weches, Queen City, Reklaw, Carrizo
					Unconformity			
		Timber belt beds	Lignitic	Queen City	Wilcox	Wilcox — Carrizo, Indio	Wilcox	Wilcox
				Wilcox				
				Midway	Midway	Midway	Midway	Midway

At the end of the period of non-deposition after the Wilcox, the East Texas basin again subsided slightly. By this time the source material being brought down by the streams changed to those types which produce the typical Lower Claiborne lithology. The Carrizo is lithologically Claiborne in appearance and was laid down in a shallow basin, probably within the zone of wave action. The Carrizo consists of alternating stratified and cross-bedded, fine- to medium-grained, clean quartz sand. No lignite is known in the Carrizo. Locally the Carrizo contains light-colored clays and volcanic ash. In places the Carrizo has been indurated, probably by circulating ground waters carrying a large amount of iron, into a hard ferruginous sandstone. This gives rise to the so-called "big rock" country in Henderson County and other places on the western side of the geosyncline.

The Carrizo is well exposed ¼ mile north of Pine Bluff on Trinity River in Freestone County. It is also well exposed on Trinity River at Green's Bluff in Anderson County. The clay industry near Athens obtains its material from clay which is probably Carrizo in age. Good exposures can be seen at the pits of the several companies. Carrizo is found near Jamestown in the northwestern part of Smith County; east of Canton in Van Zandt County; in Freestone County along the concrete highway east of Turlingen; in Gregg County, on the Longview-Kilgore road, just south of Longview; and on the south bank of Sabine River along the same road; around the town of Henderson in Rusk County; and south of Mount Enterprise on the upthrown side of the fault that traverses this section.

Wherever the Carrizo has any appreciable thickness it produces a hilly, rolling topography and a very sandy soil. Some of the highest hills in Henderson and Van Zandt counties are caused by the ferruginous sandstone member of the Carrizo. On the northern and western fronts of the East Texas basin the beginning of the Carrizo is marked by a decided escarpment.

Reklaw.[1]—The Reklaw consists of those glauconites and glauconitic clays above the Carrizo and underlying the sands and clays of the Queen City. This formation receives its name from the village of Reklaw, in east-central Cherokee County, where good exposures are found. These beds are excellently exposed in a cut on the T. and N. O. Railway right-of-way 2 miles southeast of Reklaw in northwestern Nacogdoches County. Following the shallow Carrizo seas, the basin subsided further

[1]Name proposed by the writers and approved by T. W. Stanton of the U. S. Geol. Survey Committee on Geologic Names.

and the deposits were probably laid down just beyond the zone of wave action in water not much deeper than 150 fathoms. The basal part of the Reklaw consists of 20-40 feet of brown to dark blue micaceous sandy clay with stringers of glauconite and zones of clay ironstone concretions. Above this zone occurs rather pure clayey glauconite ranging from 4 to 15 feet in thickness, containing plentiful fossils. Above this glauconite is commonly found a brown clay with streaks of sand and greensand and zones of clay ironstone concretions. The thickness of this clayey zone ranges from almost nothing to more than 100 feet. Although this section is not the same in every place, it is in a general way in accordance with the log of the Humphreys Corporation's Thompson No. 1 diamond core test, Cherokee County (Table II). Near the eastern edge of Nacogdoches County, immediately west of Attoyac Bayou, the Queen City pinches out and the Reklaw and the Weches combine to form the Cane River formation. As the contact between the Reklaw and the Queen City is a transitional zone, its position must be arbitrarily decided. It is usually selected where the glauconitic streaks end upward in the section. The Reklaw weathers rather rapidly and it is difficult to correlate the several zones at any one locality. In some places the Reklaw is somewhat thin and so severely weathered that its presence is only detected by a reddish soil and a few ledges of ferruginous sandstone with fossil casts. There is almost no commercial iron ore found in this subdivision of the Mount Selman.

The Reklaw is well exposed in many localities, some of the better sections being: on the concrete highway in Freestone County, west of Butler; at Magnolia Ferry and Pine Bluff on Trinity River; east of Athens in Henderson County; west of Quitman, and north of Winnsboro in Wood County; north of Pittsburg in Camp County; around Kelsey in Upshur County; southeast of Mount Pleasant in Titus County; on the south side of Sabine River between Elderville and Kilgore, and on Rocky Branch southwest of Willow Springs in Gregg County; northeast of Summerville in Cherokee County and in a large part of western Rusk County; around Gallatin and east and southeast of Ponta in Cherokee County, and in northwestern Nacogdoches County. A clearly exposed section also occurs 1 mile west of Jarvis on the State Railroad in Anderson County.

Kennedy recognized the formation here named the Reklaw, at several localities, but confused its position in the section.[1] He usually

[1]William Kennedy, *Geol. Survey of Texas 3d Ann. Rept.* (1892), p. 52.

TABLE II

LOG OF HUMPHREYS CORPORATION'S THOMPSON NO. 1

Location: northeast corner of William F. Williams Survey, Cherokee County, Texas
Diamond core test. Elevation, 466 feet

Depth in Feet	*Description of Formation*
24	Clay and sand
30	Glauconite with very few fossils
53	Glauconite with fossils more plentiful
73	Brown sand and silt
83	No recovery. 1¼-inch layer ironstone at 78 feet
87	Small layers glauconite
92	Brown shale with laminated gray micaceous sand
102	Brown shale with cross-bedded laminae of gray sand. Glauconite in stringers at 94, 97, 97½, and 98 feet
111	Brown shale with irregular laminae of gray sand. Glauconite stringers at 102, 103, 109½, and 111 feet
115	Sand and clay with brown laminated shale containing plant remains
133	Gray micaceous sand, with much silt and few thin layers of shale
143	Brownish-gray laminated sand and shale
153	Brown sand and shale
163	Brown shale with laminae of sand
203	Gray sand
213	Gray sand and shale with plant remains
223	Gray silty sand
318	No recovery, sand
321	Gray clay with irregular lenses of gray sand, containing plant remains
331	Brown shale with irregular lenses of sand, thin stringers of impure glauconite
341	Brownish-gray shale with laminae of sand, numerous slip joints in clay
354	Gray clay with few layers of brown shale and gray sand
364	Gray shale with laminae of sand
380	Brown shale with laminae of sand
384	No recovery, sand
389	Gray shale with laminae of sand, few thin layers of glauconite at 388½ and 389 feet
399	Brown shale with laminae of sand and stringers of glauconite fossil casts at 398
409	Same as 389 and 399
410	Brown shale with laminae of sand, fossil casts, clay ironstone at 410
414	Impure sandy glauconite containing few fossils
422	Brown shale with few fossils and some sand
432	Brown sandy shale containing thin stringers glauconite and fossils
447½	Brown sandy shale with lenses of glauconite fossils, echinoid spines
470	Gray shale containing small fossils
483	Glauconite containing many fossils including bryozoans
488	Brown shale with laminae of gray sand, fossiliferous
498	Brown sandy shale with glauconite lenses
504	Brown sandy shale with fossils
523	Brown sandy shale with stringers of glauconite
531	Sand with glauconite stringers, fossiliferous
554	Sand, no recovery, white sand in cuttings

CORRELATION

0–53	Weches	384–531	Reklaw
53–384	Queen City	531–554	Carrizo

placed it above the Queen City, mistaking the Carrizo for the Queen City.

Ordinarily the Reklaw begins with an escarpment. The formation gives rise to a moderately level and rolling topography which is not greatly different from that formed by the Queen City. The soil is sandy clay loam, with a reddish-brown color.

Queen City.—Following Reklaw time, the East Texas basin was the scene of considerably more sedimentation than adjacent areas in Louisiana. The Queen City member of the Mount Selman feathers out at Attoyac Bayou in eastern Nacogdoches County, and also decreases in thickness toward the northeast in Cass County. Although this formation was named from the town of Queen City in Cass County,[1] the real type locality is considered to be present in the central part of the basin, where the formation reached its fullest development.

The Queen City constitutes those sands and sandy clays ranging from almost nothing to 480 feet in thickness, between the top of the Reklaw and the base of the Weches greensand. The Queen City consists of local clay zones, zones of sandy clay, beds of almost pure, cross-bedded light-colored quartz sand, thin beds of lignite, and possibly two local beds of bentonitic clay. In the basin proper, the thin beds of lignite are ordinarily found between 100 and 170 feet below the top of the Weches. Good exposures of these lignites can be seen on the J. W. Elrod 100-acre tract, John Little Survey, 3 miles southwest of Brushy Creek, Anderson County, and directly east of Boggy Creek salt dome on the M. T. Gray 70-acre tract, B. H. Loftis Survey, Cherokee County. The Amerada Petroleum Corporation's Christian No. 1, at Sand Flat in Smith County, found these lignites between 160 and 190 feet below the top of the Weches. The bentonitic clays occur in many places in the Queen City, but are best developed in the zone immediately under, and within 100 feet of, the Weches. Approximately 140 feet above the main glauconite of the Reklaw and varying between 240 and 280 feet below the top of the Weches occurs a local greensand member. This member is well exposed near Omen and Arp, in eastern Smith County, and is here termed Omen from the community where it was first recognized. This greensand extends from Harrison, through Gregg, northwestern Rusk, andeasfern Smith counties, into Cherokee County. Its thickness ranges from 10 to 15 feet of partly cross-bedded, mealy, sandy glauconite. It weathers rapidly and is difficult to recognize.

The Queen City produces a rather gently rolling topography with a clayey sand soil, which is ordinarily light reddish-brown in color. West

[1]William Kennedy, *op. cit.*

of Catfish Creek and east of the Bethel salt dome in Anderson County, and on the tributaries of Catfish Creek in south-central Henderson County, the Queen City is very sandy and strongly resembles the Carrizo. Exposures of Queen City are ordinarily characteristic and easily recognized.

Only a few isolated bodies of commercial iron ore occur in the Queen City. The best ores are found in the Omen member.

Weches.[1]—Following the shallow condition of the seas during Queen City time, the basin subsided sufficiently again to cause conditions favorable for glauconitic deposition. The Weches is a remarkable deposit of rather pure clayey glauconite whose average thickness is approximately 50 feet throughout the basin proper, although in Nacogdoches and San Augustine counties its thickness increases. South of the southern contact with the Sparta, the Weches increases and the Queen City decreases in thickness. The core logs (Tables II and III) show this condition. On the northeast, particularly in Cass County, the Weches greensand becomes more sandy and cross-bedded, and the iron ore occurs irregularly throughout the formation.

The unweathered beds are greenish-blue in color, with plentiful fossils, but on exposure soon weather to a deep reddish-brown color, destroying most of the fossils present. Concretions of siderite are found almost throughout the glauconite. The resultant soil is deep red clayey loam. It is this formation which gives East Texas its characteristic red color. At the top of the Weches is a zone of laminated iron ore, ranging from a few inches to 4 feet in thickness. This limonite is the main commercial ore of East Texas and ranges from 20 to 50 per cent metallic iron. Penrose[2] attributes this iron to pyrite in a gray clay at the top of the Weches. Very little of this pyrite is seen because of the overlying iron ore which forms benches down the slopes of most of the exposures and because the pyrite weathers rapidly. This section is well exposed on the Southern Pine Lumber Company's 75-acre tract, W. F. Richardson Survey, 10 miles southeast of Palestine, Anderson County, Texas. Here the laminated ore can be seen bulging down into the gray pyritic clay. Burchard, Dumble,[3] and other investigators attribute the commercial iron to the siderite concretions and to the glauconite.

[1]Name proposed by the writers and approved by T. W. Stanton of the U. S. Geol. Survey Committee on Geologic Names.

[2]R. A. F. Penrose, Jr., "A Preliminary Report on the Geology of the Gulf Tertiaries of Texas from Red River to the Rio Grande," *Geol. Survey of Texas 1st Ann. Rept.* (1890), p. 74.

[3]E. T. Dumble, "The Geology of East Texas," *Univ. of Texas Bull. 1869* (1919), p. 319.

TABLE III

LOG OF HUMBLE OIL AND REFINING COMPANY'S J. L. BONNER NO. 1-A

Location: 1226 feet S. and 1041 feet E. from NW. corner, William Elliott Survey, Angelina County, Texas. Elevation, 204 feet

Depth in Feet	*Description of Formation*
12	Surface and sand
20	Sand
60	Sandy shale and gravel
96	Sandy shale
120	Shale with streaks of sand (sandy shale). Lower part of sand is greenish-gray
153	Hard grayish-brown shale with fossil fragments
154	Rock (brown clay ironstone)
216	Sandy shale streaks of gray sand
217	Brown clay ironstone (less than 1 foot)
233	Sandy shale
234	Brown clay ironstone (less than 1 foot)
256	Sandy shale with streaks of gray sand
261	Hard shale
277	Sandy shale (greenish), glauconitic and fossiliferous
296	Hard shale
314	Brown shale, few streaks of sand
315	Rock
328	Hard shale
330	Shale (greenish), glauconitic and fossiliferous
341	Hard sandy shale, dark, slightly greenish-gray
357	Hard shale
394	Gray shale, sticky
395	Rock
400	Gray shale, sticky
405	Gray shale
419	Gray shale, boulders
449	Hard gray shale, sticky
496	Same, fossiliferous
543	Gray-brown sticky shale, streaks of glauconite, fossiliferous; 4-inch rock at 496
564	Sandy shale, streaks of sand
575	Sand, 6-inch rock at 564
595	Sandy shale
626	Brown sand
628	Rock
634	Sandy shale
649	Shale, sticky
668	Sand, gray and brown, streaks of lignite
670	Hard shale (shells)
723	Brown sand, streaks of lignite
738	Hard sticky shale
779	Sand
799	Sticky shale
806	Brown sand
822	Sticky shale
830	Sand
845	Sticky shale
847	Glauconite greensand
850	Hard shale

TABLE III—*Continued*

Depth in Feet	*Description of Formation*
858	Greensand marl
868	Soft glauconitic shale
869	Greensand marl
901	Soft glauconitic shale
909	Greensand (glauconite)
916	Brown shale
917	Rock
919	Greensand
930	Brown shale
934½	Sandy shale, oil-bearing (Nacogdoches shallow pool, producing horizon)
939	Sandy shale
959	Dark gray shale
967	Shale and boulders
976	Glauconitic shale and boulders
1047	Sand
1055	Sandy shale
1064	Gray sticky shale with streaks of sandy shale
1095	Gray sticky shale
1098	Sand
1107	Sticky brown shale, partly glauconitic
1109	Sand
1115	Sticky shale
1116	Rock
1118	Greensand
1125	Sticky shale
1126	Rock
1141	Shale, streaks of greensand and fossils
1142	Rock
1204	Brown shale, streaks of glauconite
1208	Fossiliferous bluish-gray shale with some lime, calcareous
1223	Brown sticky shale with greensand
1264	Sand
1272	Sandy shale
1305	Water sand

CORRELATION

0-120	Yegua	976-1098	Queen City
120-575	Crockett	1098-1223	Reklaw
575-806	Sparta	1223-1305	Carrizo
806-976	Weches		

The Weches, where capped by the laminated ore, gives rise to the hilly, plateau-like topography of East Texas.

The Weches has commonly been referred to as Cook Mountain. The type locality at Mount Selman is on this deposit, but Kennedy, Deussen, and Dumble repeatedly refer to it as Cook Mountain in other localities.

The Weches has a very widespread distribution, and is ordinarily confined to the central part of the basin. Excellent exposures can be

found at almost any of the localities shown within its outcrop on the map (Fig. 1). The iron ore at the top of the Weches is the best key bed in East Texas.

COOK MOUNTAIN[1]

Sparta.—The sands and light-colored clays, amounting to 250 or 300 feet in thickness, between the Weches greensand and the Crockett clays are called the Sparta sands because they are the equivalent of the same beds in Louisiana. Following Weches time, the youngest Lower Claiborne of the basin proper was laid down. At the southern end of the East Texas basin, where the formations dip normally toward the gulf coast, the Sparta sands reach their greatest thickness of approximately 300 feet. Probably nowhere in the basin proper does the total thickness occur. The Sparta formation ordinarily occurs on the high plateau-like hills above the Weches greensand. Under certain structural conditions, as in west-central and southwestern Smith County, there is at least 130 feet of the Sparta exposed. In this low area, ranging ln elevation from 70 to 120 feet above the top of the Weches, is a sandy glauconitic zone which has been termed the Tyler member of the Sparta. This glauconitic zone is well exposed throughout the city of Tyler, and west and northwest of Swan, in Smith County, where it consists of approximately 50 feet of very sandy, partly cross-bedded glauconite, with a few clay lumps. This glauconite weathers rapidly and as yet no fossils have been found in it. Some geologists in this territory place the Tyler greensand in the Crockett formation. The writers believe this bed is a local member of the Sparta because no similar bed has been seen south at the normal Sparta-Crockett contact, and because the interval in Smith County, between the Weches and the Tyler member of the Sparta, is not great enough to represent the entire Sparta formation.

[1]Name of a high hill located about 2 miles west of Crockett, Houston County, Texas. Upon recent investigation, it has been found that the hill was named Cook's Mountain, after John T. Cook, who originally owned part of the mountain.

As early as 1889 R. A. F. Penrose made mention of this locality, on page 314 of the "First Annual Report, Geological Survey of Texas." Cook's Mountain was first designated as a formation name in 1892 by William Kennedy in the "Second Annual Report, Geological Survey of Texas," p. 52. This locality is also called "Cook's Mountain" on the soil map accompanying the "Soil Survey of Houston County, Texas," *U. S. Bur. of Soils* (1906). Alexander Deussen, *U. S. Geol. Survey Water Supply Paper 335* (1914), p. 56, uses the name Cook Mountain for this formation. In *Univ. of Texas Bull. 1869* (1919), Dumble calls the formation Cook's Mountain, as originally named by Kennedy in 1892. Alexander Deussen, *U. S. Geol. Survey Prof. Paper 126* (1924), again uses the name Cook Mountain formation.In the same year, E. T. Dumble likewise uses the name Cook Mountain, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 4 (July-August) 924, p. 428.

The name Cook Mountain is officially used by the U. S. Geological Survey.

The Sparta produces a very sandy soil. At the southern end of the East Texas geosyncline, the topography of the Sparta consists of a series of moderately rolling hills, although in the basin proper, where the sand caps the high plateaus, it is somewhat level. In the synclinal area of Smith County the Sparta produces a gently rolling topography, with hills capped by Tyler rising above the general level.

The Sparta caps all the hills or plateaus protected by the iron ore of the Weches. It is also found in the basin in a considerable area where local synclinal basins occur. The Sparta crops out in northern Sabine County and extends westward through San Augustine, southern Nacogdoches, northern Angelina, southern Cherokee, southern Anderson, northern Houston, and south-central Leon counties. The western limit of this sand has not been traced.

This sand was recognized by both Dumble[1] and Kennedy,[2] who usually referred to it as Nacogdoches in age. However, their real Nacogdoches, as defined, consisted of the transitional beds between Cook Mountain and Yegua.

Crockett,[3] including Milams[4] and Saline Bayou.[4]—The problem of the upper part of the marine Claiborne is one for paleontologists to solve. In Louisiana,[5] this series can be divided into the upper Saline Bayou, the middle Milams, and the lower Crockett, all with distinct faunal zones. In Texas these three zones are present in Sabine County, but westward the two upper members are progressively overlapped by the Yegua. Inasmuch as these three zones have not yet been thoroughly investigated, the discussion is primarily about the Crockett. Dumble's type locality of the Yegua in Lee County is Crockett in age.

If the Tyler greensand mentioned under the Sparta formation is not Crockett in age, then the upper part of the marine Claiborne is not present in the basin. The Crockett formation normally crops out south of the place where the normal, gulfward dip commences. The Crockett consists of chocolate brown and gray clay, ranging from 350 to 450 feet in thickness and containing some beds of fossiliferous glauconite with

[1]E. T. Dumble, *op. cit.*, pp. 79-80.

[2]William Kennedy, *op. cit.*, pp. 52 and 105.

[3]Name proposed by the writers and approved by T. W. Stanton of the U. S. Geol. Survey Committee on Geologic Names.

[4]Names proposed by Miss A. C. Ellisor and approved by T. W. Stanton. See Alva Christine Ellisor, "Correlation of the Claiborne of East Texas with the Claiborne of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 10 (October, 1929).

[5]See Table I for names of members previously used in Louisiana.

concretionary zones of fossiliferous brown sandy limestone. The Crockett also contains thin beds of sand, clay ironstone concretions, and in places is calcareous. The sandy glauconitic zone capping Cook Mountain in Houston County is probably a local zone and does not extend farther east than Angelina County. The gypsiferous clays south of Crockett in Houston County, which Kennedy and Dumble refer to the Yegua, have been found to contain Crockett fossils; therefore, there seems to be no logical reason for placing these beds in the Yegua. The Crockett produces a rather level and slightly rolling topography, and the soils is ordinarily sandy clay loam of a reddish-brown color.

The Crockett is well exposed at Alabama Bluff on Trinity River and southwest of Crockett, in Houston County. There is a clear section on the highway in Cherokee and Angelina counties, between Wells and Clawson. Sections of this formation are also well exposed on the Lufkin-Nacogdoches road from a point 4 miles north of Lufkin to Angelina River.

The contact between the Crockett and the Yegua is transitional. The contact is usually selected where the last macro-fossils appear. This is the usual procedure in core drilling. To attempt to call this transitional zone a separate formation or member leads to difficulty. It has been found that Dumble's[1] marine Yegua on Elm Creek in Lee County contains fauna identical with that at Alabama Bluff on Trinity River.

2. MOUNT SYLVAN DOME

Mount Sylvan, though not yet proved a salt dome, has been selected on account of the definite Weches greensand marker found on all sides. Mount Sylvan exhibits all the characteristics of a dome: low central area surrounded by a rim of hills and circular drainage, salt spring and marshy areas, high Weches greensand on the rim, local synclinal area and rim syncline, and accelerated seismograph records. All these conditions indicate, without a doubt, that this structure is a salt dome.

LOCATION AND AREA

The Mount Sylvan salt dome occurs in the western part of Smith County, Texas, 8 miles west and slightly north of Tyler, and 4 miles south and southeast of Mount Sylvan. This dome is north of the Dixie Highway and immediately east of Neches River.

The area of the dome, as defined by seismograph records, is slightly oval-shaped, with the longer axis north and south. The uplifted area covers slightly more than 3 square miles.

[1]E. T. Dumble, *op. cit.*, pp. 102-106.

HISTORICAL

Attention was first given this area in 1920 when Olfenbuttall and LeGrand drilled a 400-foot well near the edge of the dome, on the Lola V. Reese and George P. Verner 127-acre tract, Benjamin Kuykendall Survey. The Mount Sylvan prospect was recommended for seismograph exploration by E. A. Wendlandt on June 8, 1927. A seismograph crew of the Humble Oil and Refining Company verified the existence of a dome on June 15, 1927.

PHYSIOGRAPHY OF THE DOME

This dome is of the ordinary type, with a low central area surrounded by a rim of low hills. The rim is upheld by the Weches greensand and is well expressed on all sides of the dome, except where this formation has been carried away by erosion.

Black Fork Creek has broken through this rim on the northeast side and drains the central part of the dome. It also cuts through the rim on the south side, after which it flows into Neches River. It is interesting to note that Black Fork is the same stream which drains the central part of the East Tyler dome. Circular drainage is partly developed on the north and west sides.

Nearly the entire eastern part of the area overlying the salt mass is marshy, wooded bottom land. Several saline-like prairies of considerable size occur in the southeastern part of this area, as indicated on the geological map (Fig. 2).

STRATIGRAPHY OF THE DOME

The Sparta formation surrounds the dome except on the southwest. Beds of Weches age cap the rim of surrounding hills and extend away from the dome toward the west and southeast. The Queen City sands extend inward from the Weches and probably cap a large part of the uplifted central area. The Reklaw and the Carrizo possibly crop out in the central area. Recent deposits of gray clay, gravel, and iron-and-gravel conglomerate were noticed at several places (Fig. 2).

MOUNT SELMAN

Carrizo and Reklaw.—The existence of these two formations on the surface over the dome is questionable. Reklaw greensand may occur adjacent to a small fault in the southeastern part of the Willie Crenshaw 65-acre tract, John Gimble Survey.

Queen City.—Satisfactory exposures of Queen City are difficult to find, immediately over and against the dome. This is because of a

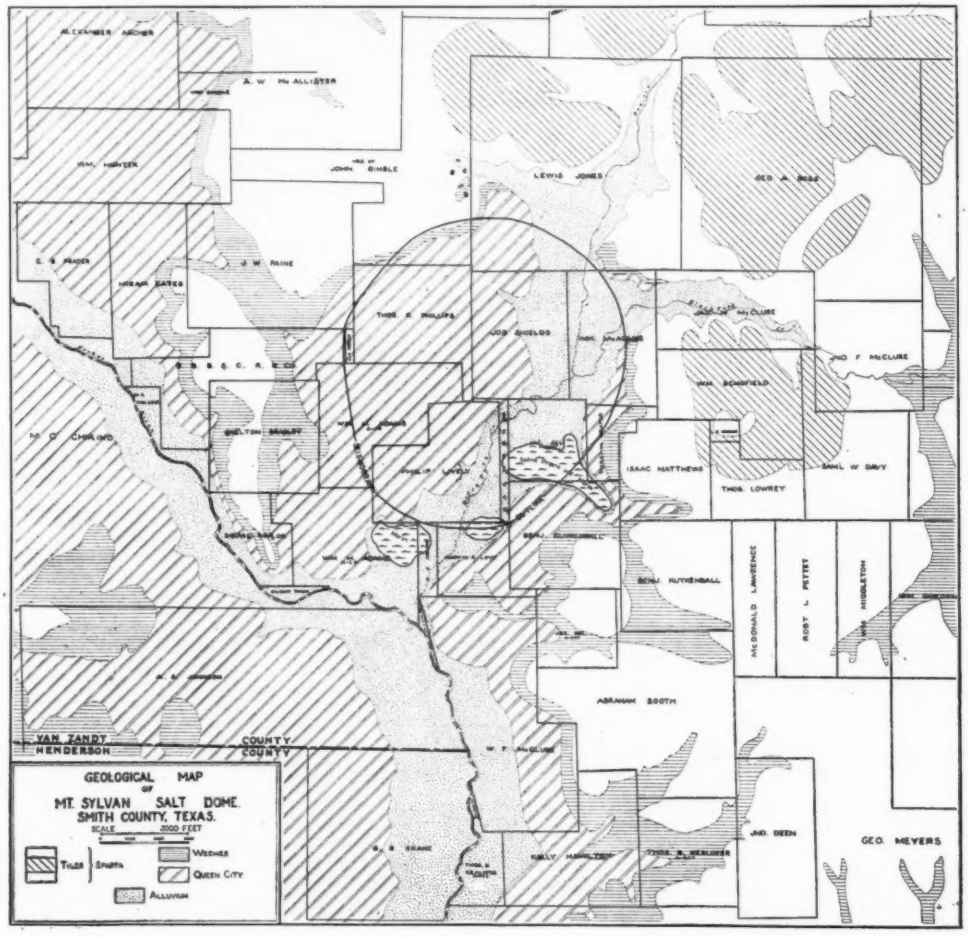


FIG. 2.—Areal geology of Mount Sylvan salt dome, Smith County, Texas.

heavy mantle of drift and re-worked material. West and southwest of the dome are many good exposures. Here the Weches is immediately underlain by thinly laminated fine sandy clay, and this in turn is followed by cross-bedded and irregularly deposited medium fine sand. Elsewhere are exposures of interstratified sand and clay and beds of cross-bedded sand.

Weches.—This greensand dips abruptly away from the dome and dips under the surface toward the north and east. The Weches is of the ordinary character and thickness, with the possible exception that on the north edge of the dome it becomes sandier and is partly cross-bedded. Typical laminated iron ore is well developed at the top of the Weches in many places.

COOK MOUNTAIN

Sparta.—The Sparta is well developed in this area, particularly northeast of the dome, where a large syncline occurs. In this synclinal area is found the Tyler greensand member, which is identical with that around the East Tyler dome and west and northwest of Swan. The base of this greensand is somewhat difficult to find, because of gradation into the underlying sands. This greensand has an estimated thickness of 50 feet and occurs from 70 to 120 feet above the top of the Weches. The Sparta below the Tyler consists of sands and light-colored sandy clays, which produce a very sandy soil.

SUBSURFACE GEOLOGY

A well was drilled in the north-central part of the Benjamin Kuykendall Survey, on the Lola V. Reese and George P. Verner 127-acre tract. The approximate location of this well is shown on the accompanying structural map (Fig. 3). This well was drilled about the year 1910, by Olfenbuttall and LeGrand. LeGrand stated that no log of the well was kept. Salt water was first encountered at a depth of 250 feet, and was present when the well was abandoned at a depth of 400 feet, because of lack of funds. This well was located off the edge of the dome as outlined by the seismograph.

Until recently, a spring of flowing salt water could be found 300 feet from the well. The spring was covered by sands accompanying the overflows of the past year, but its existence was verified by information from reliable sources, and by the presence of salt water in a hole dug at the reported location of this spring.

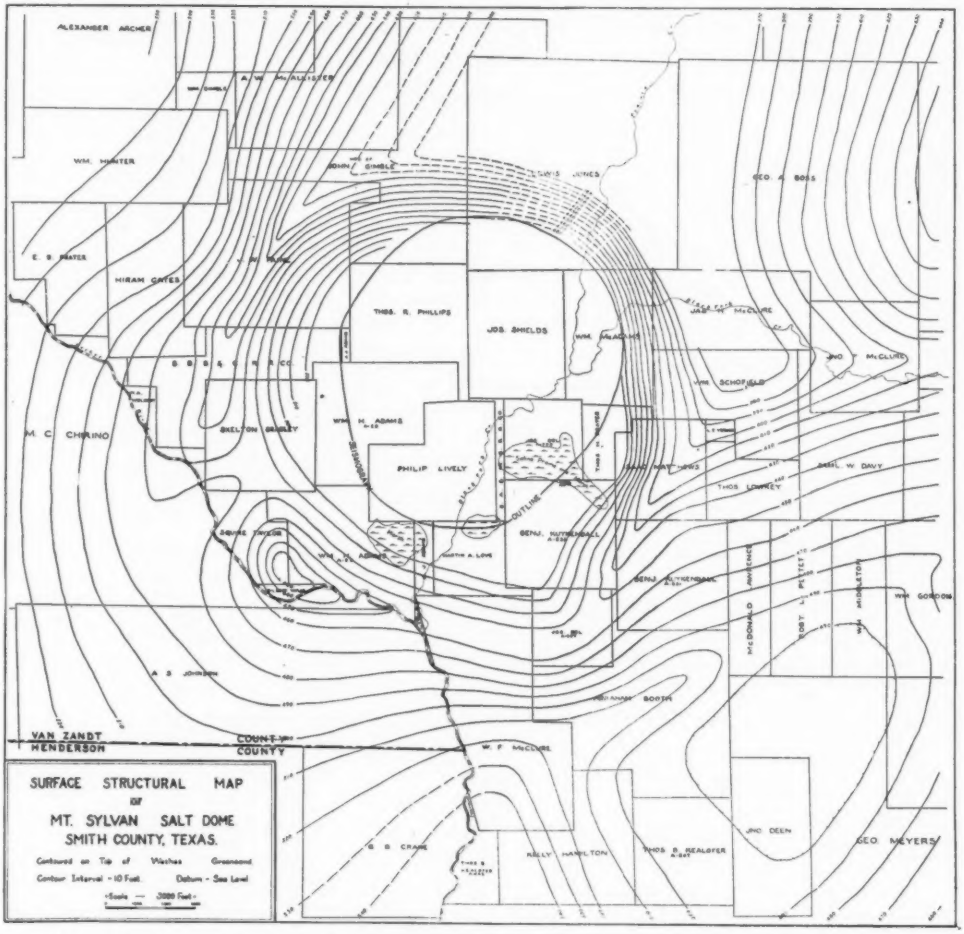


FIG. 3.—Surface structure map of Mount Sylvan salt dome, showing rim syncline surrounding salt core.

Every dome is a problem in itself and it is only after numerous deep wells have been drilled that a map can be made of underground conditions. Therefore, since no deep wells have been drilled, a hypothetical cross section has been prepared to show what might be expected in drilling in the vicinity of the dome (Fig. 4).

STRUCTURE OF THE DOME

The true amount of uplift of this dome is not reflected by the surface beds, mainly because of the unconformity between the Carrizo and the Wilcox formations, which is likewise true with nearly all the domes in the basin. The slight circular drainage toward the north and the circular drainage on the west side of the dome, the somewhat advanced age of the topography, and the presence of saline-like prairies near the dome, all seem to indicate that the depth of the salt mass is not very great. In a shallow well drilled on the Verner land on the southeast side of the dome, salt water was reported at a depth of 250 feet. Salt water was present at the time the well was abandoned at a depth of 400 feet. A salt-water spring formerly flowed in the vicinity of this well. This further strengthens the belief that the salt mass is of no great depth.

The diameter of the surface of the uplift of the Mount Sylvan dome is not more than 15,000 feet. The detailing of the top of the Weches and Tyler greensands indicates a quaquaversal fold. The contours also approximately show the edge of the dome as outlined by the seismograph. The dome occurs in a local syncline in the principal East Texas geosyncline. Elevations on the Weches in the area contiguous to the uplift range from 394 feet on the northeast side of the dome to 571 feet on the northwest side. North and northeast of the dome is a closed basin into which the dip of the Weches is relatively steep. The Tyler greensand is exposed in the greater part of this basin, and very few control points could be obtained, because the sandy phase above the Tyler is absent in most places. The Tyler greensand thickens northeast away from the domal uplift.

The high structural point of the Weches occurs on the northwest side of the dome on the east line of the H. E. Ray 20.6-acre tract, in the Heirs of John Gimble Survey, where the elevation is 523 feet. From this high point the uplifted beds become progressively lower around the dome. These edge beds dip abruptly away from the dome and attain their lowest position in the rim syncline 4,000 feet away (Fig. 3).

There is probably some slumping in the central part of the dome, but the character of the exposed material is such that it is impossible to determine the exact amount of slumping.

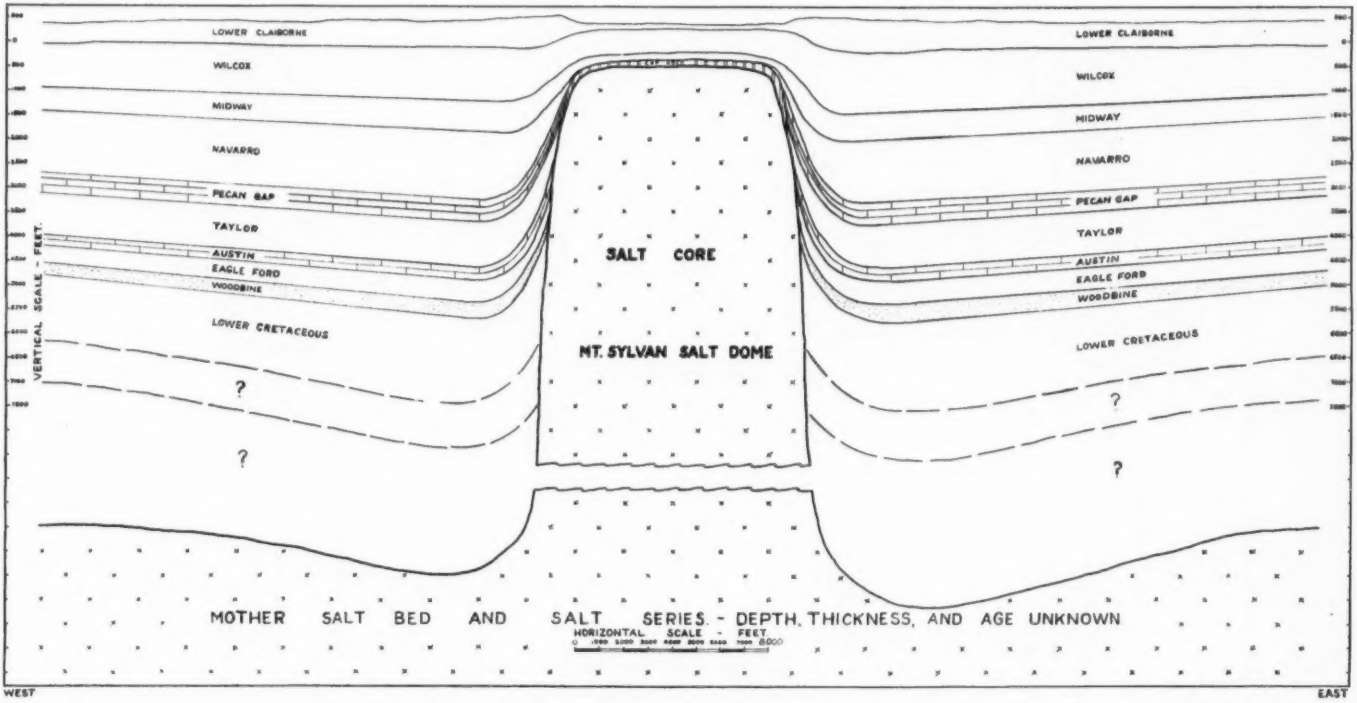


FIG. 4.—Ideal west-east section across Mount Sylvan salt dome, Smith County, Texas. Age, position, and thickness of beds below Cretaceous and above salt series unknown.

A small amount of faulting was noticed at a few places. A small fault occurs approximately 1,500 feet southeast of Mount Olive School on the Mount Sylvan road, in the Mrs. King Bunkley 158-acre tract, in the Thos. R. Phillips Survey. Two other small faults occur in the southwest part of the Lewis Jones Survey. One strikes N. 57° E. and dips 78° SE. As shown by the contours, a shallow closed basin occurs approximately 3 miles southeast of the center of the domal uplift. The topography of this particular area corresponds in a general way with this peculiar structural feature.

3. Tectonics of Salt Dome Formation

GEOLOGIC HISTORY

The evidence available indicates that a large part of the movement during the formation of the East Texas domes occurred before the deposition of the Lower Claiborne. Certain wells drilled in the low synclinal areas adjacent to one of the domes encountered a thicker section of Wilcox than is normal. This can be explained by the upward movement of the dome during Wilcox time, while the immediately surrounding area lowered, due to thinning of the mother bed of salt below by flowage into the dome. This would permit a greater thickness of Wilcox to be deposited in these local areas. Many core wells and deep borings have failed to show any evidence of erosion on top of the domes during Wilcox time.

The greatest part of the uplift occurred between Wilcox and Carrizo times. The Lower Claiborne beds show only a small amount of the movement that is evident in the Wilcox. The Claiborne beds dip gently away from the uplifted rim into the local syncline and rim synclinal areas. Over the crests of the domes many of these beds are nearly horizontal or dip in several directions, depending upon the amount of slumping.

The Claiborne beds directly over the salt core at Mount Sylvan do not give any evidence of the latest movement that has occurred on the domes. This late movement, the slumping due to solution of the salt below, is very manifest in some of the domes. On the top of the Boggy Creek salt dome in Cherokee County, at Fish Trap Hill on Neches River, a segment of steeply dipping Weches greensand is found considerably below normal. Over the top of the Whitehouse dome in Smith County, the Weches greensand is lower than on the adjacent rim. A notable example of this slumping is found on the Chestnut dome of Natchitoches

Parish, Louisiana, where the Ohio Oil Company's Thomas No. 1 encountered Cane River approximately 1,000 feet below normal.

AGE OF SALT

The domes of the basin area of East Texas have furnished no new evidence upon the age of the salt. It is still believed that the salt ranges from strata as young as Trinity to those as old as pre-Permian. The oldest formation yet encountered in drilling these domes is probably Glen Rose in age. The Humble Oil and Refining Company's Earl and Ragsdale No. 3 had questionable Glen Rose from 3,695 to 3,788 feet. The same well had considerable potash in a salt core from 3,907 to 3,916 feet. This core showed 14 per cent potassium chloride with 88 per cent of this amount present as potassium oxide.

It is believed that the original salt series is at least 1,000 feet in thickness. It would be necessary for this amount of salt to be present to account for the abnormally low wells found around some of the domes.

TECTONICS

The surface structure, as shown by the different key beds of the Lower Claiborne, offers a possible explanation of the flowage of salt during the formation of domes. The local rim synclines and local adjacent synclinal areas were recognized on the surface before being drilled. Subsequent exploration by the drill has shown that these rim synclines are accentuated in the Wilcox and that the axes of these synclines swing outward with depth. Hypothetical sections (Fig. 4 and Fig. 5), have been constructed to show this condition. The Pure Oil Company's Bruce No. 1, on the east side of the Bethel dome in Anderson County, encountered the base of the Wilcox approximately 1,000 feet below normal. The Humble Oil and Refining Company's Weinberg Brothers No. 1, on the northeast side of Boggy Creek dome, found the base of the Wilcox approximately 500 feet below normal. And 1,850 feet toward the west, Weinberg Brothers No. 2 found the base of the Wilcox 1,200 feet higher than No. 1 and was abandoned in salt at 2,891 feet. The Roxana Petroleum Corporation's Thiell No. 1, on the north side of the Oakwood dome in Freestone County, was considerably below normal.

Each dome is a study within itself; all do not exhibit the same characteristics nor do they have complete rim synclines.

Oakwood dome.—This dome has not been examined to date, although it is known from the wells drilled that a synclinal area exists on the north side of the dome. Immediately northwest in Freestone County the Queen City is lower than normal.

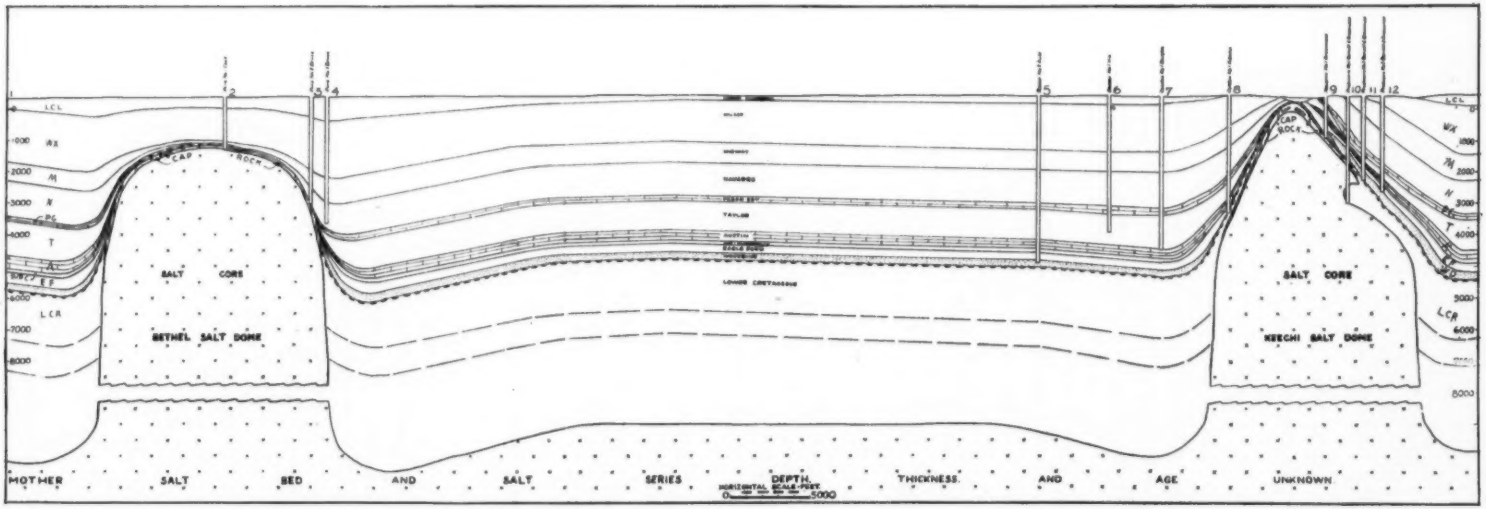


FIG. 5.—Cross section through Bethel and Keechi salt domes, Anderson County, Texas, from northwest to southeast, showing location of low structural areas around domes. Age and thickness of beds below Cretaceous and above salt series unknown. Depth in feet.

1. Roeser, Daniels No. 1, 12,500 feet northwest. 2. Pure, Cook No. 1. 3. Pure, Bruce No. 2. 4. Pure, Bruce No. 1. 5. Roeser, Auld No. 2. 6. Roeser, Via No. 1. 7. Cosden, Douglas No. 1. 8. Cosden, Adams No. 1. 9. Navarro, Greenwood No. 1. 10. Producers, Barrett and Greenwood No. 1. 11. Producers, Barrett and Greenwood No. 3. 12. Producers, Barrett and Greenwood No. 5.

LCR = Lower Cretaceous. *W* = Woodbine. *EF* = Eagle Ford. *SUBC* = Sub-Clarksville. *A* = Austin. *T* = Taylor. *PG* = Pecan Gap. *N* = Navarro. *M* = Midway. *WX* = Wilcox. *LCL* = Lower Claiborne.

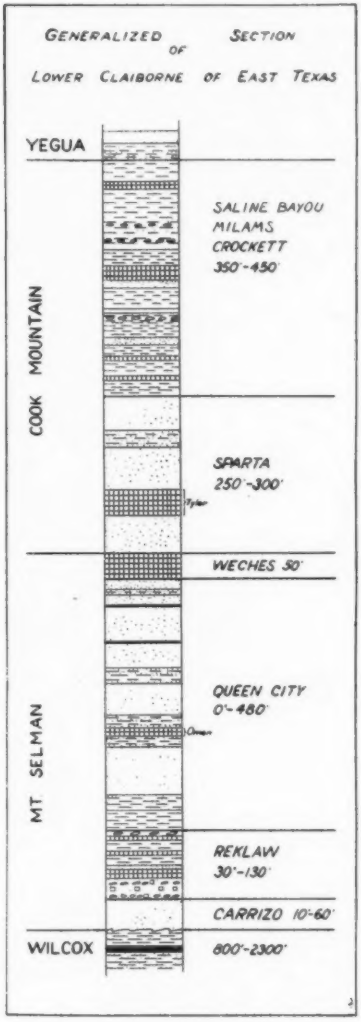


FIG. 6.—Thickness in feet.

FIG. 7.—Aerial photographic map of Mount Sylvan salt dome, Smith County, Texas, as prepared by the Edgar Tobin Aero Company, Inc., of San Antonio, Texas. Black circle indicates outline of dome.

Butler dome.—The surface has been examined in a reconnaissance manner, with no evidence to prove or disprove the presence of local or rim synclinal areas.

Palestine dome.—Not examined.

Keechi dome.—There is subsurface evidence of a local rim syncline on the west and northwest sides although no such syncline exists on the southeast flank.

Bethel dome.—On the west and east sides, the surface beds dip in toward the dome rather steeply, indicating the presence of a rim syncline. Southwest of the Bethel dome at Green's Bluff on Trinity River a 12° east dip in Wilcox and Carrizo is probably into this synclinal area. The Pure Oil Company's Willie Bruce No. 1 was considerably below normal and evidently drilled into the syncline. Since completion of the cross section (Fig. 5), The Pure Oil Company's Bruce No. 2 has encountered the following section, which would necessitate making a change in the salt outline on the east side of this dome. This test had Midway from 2,355 to 2,801 feet; Navarro, 2,801 to 3,447; anhydrite, 3,447; salt, 3,452 to 3,512, and to date is still drilling in basal Navarro from 3,520 to 4,187 feet. This section indicates a condition similar to that found on the southeast side of Keechi dome.

Brushy Creek.—Although not yet proved as a dome, Brushy Creek has a rim syncline on the west and north sides, and there is a large synclinal area between this locality and the Boggy Creek dome.

Boggy Creek dome.—The northeast, northwest, west, and southwest sides of this dome exhibit rim synclinal conditions. Immediately north and southwest are large synclinal areas, and immediately on the east the surface beds are high.

Brooks dome.—Not yet examined.

Bullard dome.—On the northwest side of this dome is a slight rim syncline, and on the northeast the beds dip into a local synclinal area. The surface beds are high on the south.

Whitehouse dome.—The Lower Claiborne beds dip away into rim synclines and adjacent synclinal areas.

East Tyler.—This dome is nearly circled by a rim syncline with local synclinal areas on the west and northeast.

Steen.—Rim synclinal areas are found on the south and west sides of this dome, with a local synclinal area on the southwest.

Haynesville.—The Haynesville dome is the type locality for rim synclines. Here the Weches dips into the rim syncline from all directions and is considerably below normal.

Grand Saline.—Low Carrizo sand shows the presence of synclinal areas east and south of this dome.

Larue.—The Queen City formation around this dome has not been detailed sufficiently to discuss the synclinal areas.

It is believed that the sedimentary salt series is at a depth of 10,000 feet or more, because of the stock-like type of these domes.[1] This estimate is based on the fact that in Germany the domes of stock-like type occur in the deeper part of the basin where the original salt series is buried at a great depth, whereas the salt anticlines occur in a shallower part of the basin. The overlying beds dip moderately into the geosynclinal area and are only gently folded. The evidence available is against the location of the domes on the crests of anticlines similar to those in Germany and Roumania. They could occur in this manner only if the salt series were folded into anticlines before Glen Rose time, and if no further movement occurred until most of the overlying beds were laid down. It is believed that the domes are situated on fault planes or points of weakness below the salt series, and with these initiating movements, the salt is forced upward in a plastic condition by the downward push of a settling basin and by isostatic pressure.

The salt probably starts its upward course along these points of weakness by flowing in from all directions. The thinning of the adjacent salt series gives rise to the rim syncline areas.[2] As the upward growth continues, the salt moves in from some directions easier than from the other directions, giving rise to the local synclinal areas. Sufficient subsurface information is not available to compare the amount of salt in the salt core with the amount of depression in the rim synclines and synclinal areas. On account of the magnitude of some of the synclinal areas (theorizing that they are caused by salt flowage rather than other tectonic conditions) it is believed that considerable salt has been carried away in solution during the penetration of artesian water sands and by normal surface action on these domes with salt cores close to the surface. Some will contend that the thinness of the anhydrite cap on these domes does not favor any great loss of salt by solution. The salt cores obtained from these domes have been relatively pure and it is almost impossible at this time to state how much salt must be carried away in

[1]Donald C. Barton, "The American Salt Dome Problems in the Light of the Roumanian and German Salt Domes," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9 (December, 1925), pp. 1261-62.

[2]Hans Stille, "The Upthrust of the Salt Masses of Germany," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 3 (May-June, 1925), p. 434, Fig. 5b.

solution to leave the amount of anhydrite present. It is highly probable that the domes on the Gulf Coast have undergone greater solution than is at present believed, and that with deeper drilling a similar set of rim synclines, local synclinal areas, and adjacent high areas will be found.

SIGNIFICANCE OF MICRO-CRYSTALS OF CARBONATES IN BITUMINOUS SHALES. A PRELIMINARY NOTE[1]

JUN-ICHI R. TAKAHASHI[2]
Sendai, Japan

ABSTRACT

Extremely minute crystals of carbonates are found embedded in the matrices of the Fushun shales. They are also found, in varying degree, in the oil shales from Colorado, Scotland, and elsewhere. A preliminary investigation reveals that those occurring in shales of terrestrial origin are mostly sideritic, and those in the marine kerogen shales are largely dolomitic.

INTRODUCTION

Numerous micro-rhombs of carbonates, when highly magnified under the microscope, are ordinarily found in oil shales of terrestrial origin. This is also true with certain types of the marine kerogen shales, as previously described by the writer[3] with the designations "calcite," or "dolomitic rhombs," without further qualification. There seem to be two kinds of carbonates, however, in the bituminous shales that have been examined subsequently by the writer. That is, those rhombs occurring in oil shales of terrestrial deposits are mostly sideritic, and those in marine kerogen shales are largely dolomitic. As these minerals are to be regarded as the primary constituents of the rocks in which they are found, these facts suggest the different environments under which the deposition of the minerals took place.

Little attention has hitherto been paid to studies of the mineral constituents of oil shales, except for the purpose of utilizing the spent shales (ashes). These studies seem, however, too important to be neglected in obtaining high percentage of the saturated hydrocarbons in the distillation of oil shales, because of the thermal behavior of certain mineral constituents, which are sensibly affected by heat. The writer, a few years ago, tried to get some light on this point, by distilling various

[1]Manuscript received by the editor, June 10, 1929.

[2]Tohoku Imperial University.

[3]J. Takahashi, "The Marine Kerogen Shales from the Oil Fields of Japan," *Sci. Rept. Tohoku Imp. Univ.*, Ser. III, Vol. 1, No. 2 (1922).

mixtures of crude oils and mineral substances such as calcite, acid earth, et cetera,[1] with the result that certain minerals acted with the vaporizing oils either as positive or negative catalyzers. Although the bitumens in the various oil shales are not widely different in their compositions, their mineral constituents vary remarkably with different shales. The effect of the mineral substances in oil shales on distillation, therefore, must be reserved for future investigations.

In the present paper, it is the writer's intention to give a general outline of the carbonate micro-crystals in the various kinds of bituminous shales observed.

CARBONATE MICRO-CRYSTALS IN OIL SHALES OF TERRESTRIAL ORIGIN

Oil shale from the Fushun coal field, Manchuria, is generally accepted as a terrestrial deposit of Tertiary age. Its chemical composition is given in Table I, together with those of several other oil shales for comparison.

TABLE I

CHEMICAL COMPOSITION OF TERRESTRIAL OIL SHALES

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SiO_2	61.00	55.6	49.72	75.80	48.8	45.8	38.9	51.17
Al_2O_3	20.60	34.77	35.60	19.10	19.9	16.4	12.4	13.97
Fe_2O_3	13.40							10.49
MnO	.....	.....	.....	.....	.....	.....	.....	0.16
MgO	4.75	tr	2.20	0.9	8.6	7.9	4.9	0.97
CaO	0.94	1.15	2.40	1.4	16.6	23.9	38.3	0.81
TiO_2	.....	.....	.....	.....	.....	.....	.....	0.42
L.Ig.	.....	.....	.....	.....	.....	.....	.....	20.28
Total	100.69	90.52	89.92	97.20	93.90	94.00	94.5	98.27

(1) Ash of Fushun shale, analyzed by the Research Inst. of S. Manchurian Railway Company.
(2) Ash of a good average of the Scotland shales, by Conacher.
(3) Ash of Broxburn shales, Scotland, by D. R. Stuart.
(4) Ash of Casmalia shale, Calif., U. S. A. (T. B. Brighton).
(5) Ash of De Beque shale, Colo., U. S. A. (T. B. Brighton).
(6) Ash of Dragon shale, Utah, U. S. A. (T. B. Brighton).
(7) Ash of Green River shale, Wyo., U. S. A. (T. B. Brighton).
(8) Fushun oil shale, analyzed by T. Yagi.

As shown in Table I, the ash of the Fushun shale is closely allied to that of the Scotland shales, though the former contains more magnesia

[1] J. Takahashi, "On the Effect of Mineral Substances on the Thermal Decomposition of Bitumens. A Preliminary Note," *Sci. Rept. Tohoku Imp. Univ.*, Ser. III, Vol. 2, Nos. 1 and 2 (1924).

(1, Table I) than the latter. Although the matrices of the latter generally consist of clayey substances, extremely fine fibers of sericite and chlorite are predominant in the former. Many Colorado shales are calcareous and relatively rich in magnesia, with calcium sulphate commonly present. The Casmalia shale (4, Table I) is not to be classed as a kerogen shale. It is a common variety of the Monterey shale which is a marine sediment, as is shown in its chemical composition.

The Fushun shale, highly magnified (above 200 diameters), reveals numerous crystalline grains embedded in the matrix. Between the crossed nicols these crystals manifest the characteristic, high birefringence of the carbonate minerals. They are either rhombohedral in form, or of combined forms (0001) and probably (0881) giving rise to almost rectangular outlines. The crystals are generally built up of sub-individuals, and their faces are ordinarily curved; hence, they may appear as irregular or sub-spherical grains, their marginal parts being obscured by the matrix in which they are embedded. The crystals range in their diameters from 0.01 to 0.8 mm., with an average of 0.02 mm., numbering 10-30 grains of such crystals in each 2.5 mm. square. As the contents of CO_2 in the shale amounts to 1.16-1.50 per cent, the total amount of such carbonate mineral may be appropriately calculated as 2-4 per cent.

Many of the crystals, ordinarily transparent and colorless, with a very slight bluish tint, and a few with a faint pleochroism, are stained reddish-brown on their surfaces. With the microchemical tests, they are appreciably affected neither by organic solvents nor by caustic alkalies, but are slowly dissolved by hydrochloric acid. In a piece of the shale immersed in hydrochloric acid and kept for 30 minutes at 60° C., almost all of the crystals are found dissolved, or coated with iron oxide. As will be mentioned later, the crystals become altered into reddish-brown spots (rhombs, or rectangular in outline) when the shale is heated for a long enough time at temperatures of more than 500°-600° C. The indices of refraction of these micro-crystals vary according to their orientation, ordinarily with their lowest indices nearly equal to, or even slightly higher than, the matrices in which they are found embedded. Owing to the minuteness and the curvature of the crystals, associated with the tendency to break into irregular grains along the boundary lines of their sub-individuals, it seems almost impossible to determine their indices with accuracy. The results of the measuring, however, by the immersion method, are tentatively given here:

$N_{min} = 1.590$ $N_{max} = 1.80$ (< 1.85, > 1.723),— namely,

with the birefringence higher than 0.2. In the indices of refraction, these crystals almost approach those of siderite, though *MgO* in moderate quantity, and *CaO* in trace, besides much *FeO*, are found through the microchemical tests. Thus the crystals may be classed as impure siderite, or as iron-rich breunnerite, probably containing more iron than the normal pistomesite, a sub-type of the latter.

Similar micro-crystals are found with similar occurrence in the oil shale of Tremembe, São Paulo, Brazil. According to Dean Winchester, to whom the writer is indebted for the specimens, the shale is a recent deposit in the intermittent shallow lake where, during the wet season, they are crowded in with various water plants, fishes, and other organisms.

The Tertiary oil shale from De Beque, Colorado, Parachute, Colorado, Green River, Wyoming, and Dragon, Utah, also contains analogous micro-rhombs (0.1 mm. diameter, average) embedded in their matrices, which are commonly calcareous. The determination of its mineralogical character, however, is reserved for future studies.

The sideritic micro-crystals are also found in many specimens from Scotland. Besides micro-crystals embedded in their matrices, larger crystals are also found sporadically. In the cannel coals, like those of Wigan, England, and Schlege, Silesia, siderite rhombs and concretions are commonly found approaching in their appearance those occurring in the "black band" iron carbonate of Paleozoic age. The Ohio shale, which is of Devonian age, likewise contains rhombs of an analogous mineral (Caterburg, Indiana).

MICRO-RHOMBS IN MARINE KEROGEN SHALES

The siliceous shale from the Michikawa oil field, Akita Prefecture, which is black and flinty in appearance, contains a small quantity of kerogen. The chemical composition is shown in Table II, together with those of shales of similar nature. The rhombs of carbonate mineral are found here and there in such marine shales with siliceous, marly, or clayey matrices. They resemble in their mode of occurrence those in the Fushun shale previously described, although the rhombs in the marine kerogen shales may be larger in size, many having zonal structure similar to that of dolomite. Their indices of refraction, so far as measured approximately, are largely coincident with the Michikawa shale, that is

$$N_{min} = 1.510 \qquad N_{max} = 1.698$$

The maxima of the indices may range a little more than the value above, with the average birefringence 0.18-0.17.

In the flinty shale of Michikawa are sporadically found crystals of glassy feldspar which appear as if they had been entombed in the oozy matrices, directly after their ejection from a volcano. Besides, there are found, rather sporadically, the remains of *Radiolaria* and *Foraminifera*, many of the former being replaced by secondary calcite, and inside the shells of the latter may be seen ankeritic rhombs. Glauconite, which abounds in similar shale of Nishikurosawa of the same prefecture, is rarely found in Michikawa shale, although micro-globules of iron sulphide are common in both.

The micro-rhombs, examined microchemically, show the content of a moderate quantity of *FeO*, besides a considerable amount of *MgO* and *CaO;* the mineral thus may be classed as dolomite, more or less ankeritic. Similar micro-rhombs, with an average diameter of 0.01 mm., are found also embedded in the matrix of the cherty shale from the Ventura oil field, California, which contains the remains of *Foraminifera* and a trace of kerogen.

The so-called oil shale from Wanifuchi and Udo in the Prefecture of Shimané, which is in reality a marine kerogen shale containing the remains of *Foraminifera*, likewise contains micro-rhombs of similar nature, embedded in siliceous or marly matrix.

TABLE II

CHEMICAL COMPOSITION OF MARINE OIL SHALES

	(1)	(2)	(3)	(4)	(5)	(6)
SiO_2	76.43	55.91	71.93	74.03	68.08	65.99
Al_2O_3	2.01	6.59	10.59	5.61	14.72	6.65
Fe_2O_3	2.20	4.92	5.62	13.77	6.18	2.84
MgO	1.98	1.38	1.11	2.08	1.85	1.10
CaO	2.18	1.53	1.93	0.84	0.89	5.31
Alkalies	2.01	.....	.....	.....	.....	.....
L.Ig.	12.33	25.57	7.77	2.63	6.57	16.37
Total	99.14	95.90	99.05	98.96	98.29	98.26

(1) Black, flinty shale, Michikawa, Akita.
(2) Monterey shale, Santa Maria, Calif., impregnated with petroleum, sometimes called "oil shale." Contains 0.33 per cent of TiO_2.
(3) Marine kerogen shale, Wanifuchi, Shimané.
(4) Same as the above.
(5) Marine kerogen shale, Udo, Shimané.
(6) Cherty shale of dark color, Ventura, Calif. All these were analyzed by T. Moriya, formerly assistant to the writer.

ORIGIN OF THE MICRO-RHOMBS

The fact that the kerogen shales contain, besides kerogen, various mineral constituents which are easily liable to thermal decomposition, and the fact that the shales are ordinarily impervious to water, suggest that their properties inherited from their original saprolite are still retained by the shale, without being subjected to any violent metamorphism, except for a partial diagenetic alteration. As the micro-rhombs here described are to be regarded as a primary constituent of the shale, their presence in the shale may be taken as criteria for discussing the condition of the environment under which the shale was deposited. Further, the mechanism of the bituminization, which is by no means clearly understood at present, may be made clear if the mode of occurrence of such minerals be made known first, associated with their paragenetic minerals such as kerogen, iron sulphide, gypsum, calcite, et cetera, besides their fossil content.

As to the origin of dolomite, opinions differ widely among the investigators. Viewed from their fossil content, there seems to be no remarkable difference between limestone and dolomitic rocks in the conditions of the environment under which these rocks were deposited. According to Twenhofel,[1] the greater part of the calcareous rock in America belongs either to limestone containing less than 10 per cent of dolomite or to dolomitic rock with its calcite content less than 10 per cent; the rock consisting of equal proportions of calcite and dolomite being rather exceptional. This suggests that the subaquatic formation of dolomite, or dolomitization, is produced under special conditions.

Dolomite is generally accepted as a marine formation. Yet it is frequently said that there is little possibility of its primary precipitation under the sea. The ordinary content of iron carbonate, 1-10 per cent by weight, in dolomite, strongly suggests its formation under a reducing condition. Such condition is most feasibly realized under subaquatic anaerobic decay, due to the biochemical decomposition of the organic débris entombed. The idea seems specially acceptable in the matter of the micro-rhombs occurring in certain marine kerogen shales.

The matrices of the shales from Michikawa (Akita), Ventura, (California) and others, in which the rhombs of iron-bearing dolomite are found, consist largely of extremely fine detritus of volcanic origin and its decomposition products which are siliceous by nature, contaminated with some amount of colloidal silica of organic origin, besides organic

[1] W. H. Twenhofel *et al.*, *Treatise on Sedimentation* (1926), pp. 264-65.

débris and fossils. The micro-globules of iron sulphide, likewise a product of the reducing decomposition, were formed, partly at least, at the same time as, or even prior to, the time when the precipitation of the dolomitic crystals took place.

The *MgO* content of the dolomite may be considered to have been derived from the shells of *Foraminifera* which are ordinarily found in such shales. There is, however, little evidence for thinking that the shells were subjected to any considerable chemical action during the earlier stage of sedimentation, as may be perceived from microscopic examination. The dolomite rhombs, however, are found developed in the matrices independently of the foraminiferal shells. The possibility, therefore, is that either these rhombs were formed originally as such, or were at first precipitated as calcite rhombs which had gradually become dolomitized.

The probability, however, is that the former of these two theories is true because of the fairly identical chemical compositions and the indices of refraction of the dolomitic rhombs, and because of the fact that it is relatively easier for the magnesia dissolved in sea water to combine with colloidal minerals than it is for the calcite crystals.

Siderite is known to be formed under the reducing conditions due to the anaerobic decay of organic substances. Such environment of sedimentation may be found in certain swampy areas, marshes, flood plains of a river, lagunal seas, et cetera. A chemical equation generally accepted to show the formation of siderite under such conditions is cited:[1]

$$2Fe_2O_3\ 3H_2O + C = 4FeO + CO_2 + 3H_2O$$

$$4FeO + 4CO_2 = 4FeCO_3$$

If the bodies of water are very shallow, or if they are intermittently flooded, an excess of carbon dioxide may be contained in the waters at one season, so as to keep the iron carbonate in the water in the form of bicarbonate, which may, in turn, be precipitated again in the succeeding season when the flourishing vegetation uses all of the carbon dioxide. Under such conditions, if the iron sulphide once formed be oxidized to form iron sulphate, siderite may be produced in the presence of calcite:

$$FeSO_4 + CaCO_3 = FeCO_3 + CaSO_4$$

In short, for the formation of siderite an environment favoring reducing conditions is required. In general, however, its formation under marine conditions is rather exceptional.

[1]W. H. Twenhofel, *op. cit.*, p. 332.

The carbonate micro-rhombs in the Fushun shale are probably siderite, containing a moderate amount of magnesium, besides a trace of calcium. The amount of magnesium seems to be less than that of the pistomesite ($MgCO_3$ $FeCO_3$) subtype of breunnerite. Among the paragenetic minerals, the micro-globules of iron sulphide are less plentiful in that shale than in the marine shales of similar nature. The amount of MgO is considerable in the analysis (1) of Table I, but moderate in the analysis (8) recently made by T. Yagi. A fuller account on this point will be given in a later report after the completion of other analyses which are now being performed.

The writer is not certain of the water conditions under which the Colorado shales were deposited. The mineralogical characters of the micro-rhombs and of the matrices, which are apparently dolomitic, are reserved for future studies.

Those micro-rhombs occurring in the Paleozoic oil shales, cannel coals, and allied rocks are mostly sideritic, suggesting a mode of formation not very different from that of the Fushun shale and of the Tremembe shale.

EFFECT OF SIDERITIC RHOMBS ON DISTILLATION OF OIL SHALE

The amount of carbonate micro-rhombs in Fushun shale probably does not exceed 2-4 per cent. The rhombs are, however, uniformly distributed in the matrix. And the idea that the bitumens distilling from the shales may be affected by these minerals seems by no means unreasonable.

Several investigations of the thermal properties of dolomite have been reported; a brief summary is also given in the paper recently published by H. Kani,[1] in connection with experiments carried on under the direction of Prof. Kozu. In general, dolomite is totally decomposed at temperatures higher than 800° C.; magnesite, at 600° C.; and siderite, at 500° C.

The highest temperatures used in ordinary distilling methods of oil shale, on the contrary, vary from 500° or 600° C. to over 800° C. As the greater parts of the bitumens become vaporized at temperatures not exceeding approximately 500° C., siderite should not have any effect on the distillation of bitumens. A few preliminary experiments recently made by the writer, however, show that this is not true.

Microscopic sections were prepared from a piece of Fushun shale, which had previously been distilled in a fused-silica flask at temperatures

[1] H. Kani, *Jour. Tokio Geol. Soc.*, Vol. 25, No. 416 (1928).

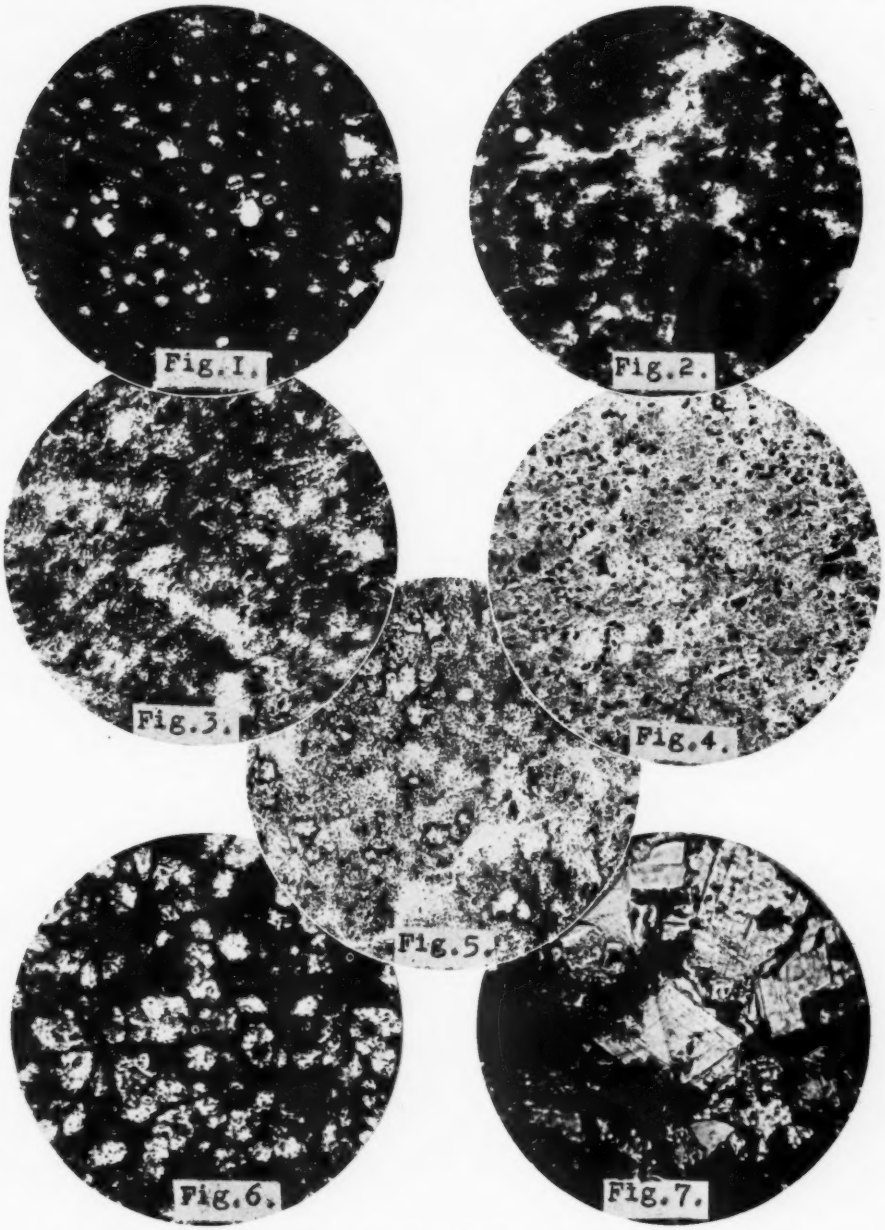


FIG. 1.—Micro-photograph of the oil shale from the Fushun coal field, southern Manchuria. The white spots, irregularly rhombic, rectangular, or sub-spherical, are sideritic micro-crystals. Magnified about 100 diameters.

FIG. 2.—Same as Figure 1, but treated with hot HCl for 30 minutes. The micro-crystals mostly dissolved, the remainder being encrusted with reddish-brown iron oxide. Magnified 100 diameters.

FIG. 3.—Same as preceding, but distilled at temperatures varying from 300° to 350° C., for 30 minutes. The matrix is discolored by the carbonaceous substance (bitumens), in which are found reddish-brown spots in place of sideritic rhombs. Magnified 100 diameters.

FIG. 4.—Same as preceding, distilled at 500° C. for 40 minutes. The carbonaceous materials discoloring the matrix in Figure 3 are largely eliminated, showing clearly the iron oxide spots which retain their original forms of "siderite," but remarkably contracted in size. Magnified 100 diameters.

FIG. 5.—Micro-photograph of the marine kerogen shale from the Michikawa oil field, Akita, Japan, showing dolomitic rhombs, embedded in siliceous matrix. Magnified 30 diameters.

FIG. 6.—Same as preceding, magnified approximately 60 times in diameter, showing rhombs consisting of sub-individuals.

FIG. 7.—Same as preceding, magnified approximately 70 times in diameter, showing a dolomite crystal with zonal structure, and feldspar crystals.

between 300° C. and 350° C. for approximately 30 minutes. On microscopic examination, the sideritic crystals in the shale are found almost wholly decomposed, altered to iron oxide, still preserving their original outlines but much contracted in size. The matrix is darkly discolored by the carbonaceous residues (bitumens). The shale distilled at the temperature of 500° C. for 30 minutes has largely lost the carbonaceous substances in the matrix, and the minute spots of the iron oxide become clearly visible, as shown in the micro-photograph (Fig. 4, Plate 15). In those distilled at temperatures higher than 800° C. for a long enough time, the spots of iron oxide greatly increase in number, due to the oxidation of the micro-globules of iron sulphide.

The oxidation of such sideritic grains and micro-globules of iron sulphide at relatively low temperatures may be explained by the presence of sulphurous gases (H_2S and SO_3) and the acidic gases evolving at the low temperatures because of decomposition of the organic substances or the sulphur in the free state, which are contained in the shale.

At any rate, the production of the iron oxide grains in the nascent state at temperatures of approximately 300° C., at which temperatures the distillation of the bitumens is most effective, should not be neglected in the study of the distillation of oil shale. It is almost unnecessary to add that iron oxide is one of the effective catalyzers in the artificial production of the hydrocarbon oils.

The effects of certain colloidal (gel) minerals consisting of the matrices of the shales in which the kerogen bitumens are found intimately mixed are also to be considered. This, however, may be reserved for future studies.

SUMMARY

1. Micro-rhombs of carbonate minerals are commonly found in bituminous shales.

2. Those occurring in oil shale of terrestrial origin, that is, of the fresh-water deposits—the Fushun shale for example—are found to be largely sideritic, richer in iron than the pistomesite subtypes of breunnerite.

3. Those found in certain types of the marine kerogen shales are mostly dolomitic, or possibly ankeritic.

4. These minerals are found decomposed at relatively low tempertures, to form iron oxide due to the evolving of acidic or sulphurous gases; and the importance of this iron oxide as a catalyzer on the thermal decomposition of the bitumens is suggested. These minerals constitute only a small part of the shale, but are uniformly distributed in the shale.

5. The importance of such minerals for studies undertaken to make clear the environment under which the various shales were deposited is to be reserved for future investigations.

GEOLOGICAL NOTES

DARST CREEK FAULT, GUADALUPE COUNTY, TEXAS

Direct credit for the discovery of production in the Darst Creek area, 10 miles southeast of Seguin in Guadalupe County, Texas, properly should go to Dilworth Hager. Although Alexander Deussen in *U. S. Geol. Survey Professional Paper 126* showed this fault crossing Guadalupe River, it was not until September, 1928, that the fault was outlined in detail by plane table and the areal distribution of beds mapped to indicate that there was closure on that fault. This work was done by Dilworth Hager assisted by Robert Franks. After the work was completed a block of leases covering the structure was taken by Weinert and Moore in association with Mr. Hager. Following the completion of the block Mr. Hager accompanied P. F. Morse (deceased) of The Texas Company, and L. F. McCollum, of the Humble Oil and Refining Company, and explained to them his interpretation of the structure. The Texas Company and the Humble Oil and Refining Company then secured the bulk of the leases along the fault and The Texas Company assumed a drilling obligation in connection with their part of the deal and made a location on the Dallas Wilson tract.

The well came in on July 18, 1929, producing at the rate of 1,200 barrels per day from the Edwards limestone. Since the completion of this well, development has been slow, due to a mutual agreement between the companies. It is probable that this area will develop into a field of considerable length and that the structure will be found similar to that in the old Luling field and the Salt Flat field on the northeast.

CHAS. H. ROW

SAN ANTONIO, TEXAS
August 1, 1929

OKLAHOMA CITY POOL, OKLAHOMA

The area of central Oklahoma, prior to the discovery of the Greater Seminole field, was not considered favorably by operators, primarily because of the great depth to which it is necessary to drill in order to reach even the shallower Pennsylvanian sands. After the discovery of

the original Seminole City pool and its extension about 15 miles due southwest (Pearson Switch), as well as the discovery of deep "Wilcox" sand production in the Lovell area (T. 19 N., R. 4 W.), the larger companies mapped surface geology west from the Seminole pools and southeast from the Lovell pool.

In the fall of 1927 the Indian Territory Illuminating Oil Company mapped the Oklahoma City structure and blocked all available acreage, controlling about 75 per cent of the leases located within the last closure. The first well was commenced in the center of SE. ¼, SE. ¼, Sec. 24, T. 11 N., R. 3 W., Oklahoma County, June, 1928, and was completed in December of the same year, making 6,000 barrels from 6,420 feet, thus opening a pool of major importance.

SURFACE

The outcropping beds are of Permian age on the contact between the Garber and Hennessey formations of the Enid group. It is of interest to note that both the Lovell and the Garber fields were also mapped along the same Garber-Hennessey contact. The Oklahoma City surface structure has 110 feet of closure, and as indicated on the Indian Territory Illuminating Oil Company map (Fig. 1), it has a north-south trend, but toward the north-northeast and northeast it dips off very sharply, turning the north end of the structure due northwest. The surface structure of the Oklahoma City pool resembles very closely that of the Garber field, that is, closures are about the same, trends are north-south, and the sharpest dips are on the northeast side of the folds. Also in both pools the northeast dips reflect sharp scarps or faults in the Ordovician, which have been proved in Garber and are already indicated in the Oklahoma City pool.

STRATIGRAPHY

The geological column of the Oklahoma City pool is here presented in a very brief form, indicating respectively the depth in feet of corresponding formations in the Garber pool.

In the Garber pool, now thoroughly developed, major production has been developed in several horizons in addition to the "Siliceous lime": Oswego limestone (locally), Layton and upper Tonkawa sands, as well as several sand bodies in Upper Pennsylvanian and Lower Permian. In the Oklahoma City pool, so far, the upper horizons have been disappointing. Gas has been found in large quantities in the Endicott, Tonkawa, and Layton sands, with only a little oil. Inasmuch as drilling

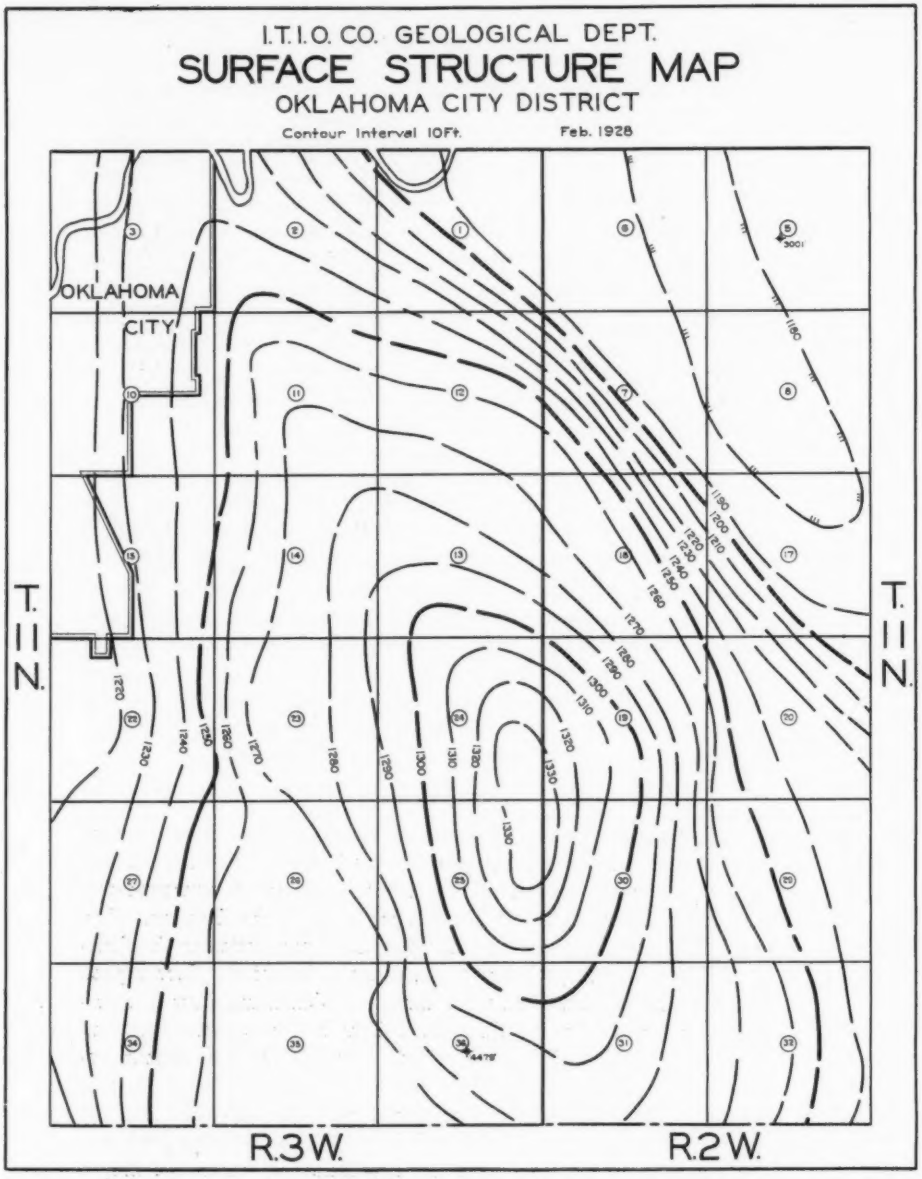


FIG. 1—Contours drawn on beds of Permian age on contact between Garber and Hennessey formations of the Enid group. Width of area, 5 miles. Map published by permission of the geological department of the Indian Territory Illuminating Oil Company.

	Oklahoma City (Surface elevation 1,300 feet)	*Garber (Surface elevation 1,100 feet)*
Garber-Hennessey contact	Surface	Surface
Base of Permian	2,200	1,450
Pawhuska series	3,200-3,600	2,200-2,350
Carmichael-Endicott sand zone	3,950-4,100	2,650-2,800
Upper Tonkawa, limestone and sand	4,300-4,570	3,000-3,100
Lower Tonkawa, limestone and sand	4,750-5,000	3,250-3,350
Layton sand	5,200-5,250	3,600-3,700
Checkerboard limestone	5,250-5,300	3,950-3,975
"Big lime"—Oswego series	6,030-6,070	4,050-4,200
Cherokee shale. Base of Pennsylvanian	6,070-6,170	4,200-4,280
Detrital zone	6,170-6,220	4,280-4,300
"Siliceous lime"—Arbuckle (Ordovician)	6,220- ?	4,300-5,500
Granite	8,500 ?	5,500

in these sand bodies developed holes full of water under the gas, flank production from these sands is rather doubtful at this time, though it may be locally developed in sealed sand lenses, particularly within the Cherokee shale section. The difference between the Garber and the Oklahoma City pools can possibly be explained by the much sharper structure in Garber pool with the resultant pronounced faulting, the fault zones allowing oil from the Ordovician to migrate to the upper beds. In the Oklahoma City pool, the buried Ordovician hill is considerably flatter than in Garber and the resultant fracturing of the Pennsylvanian beds has been sufficient for migration of gas only.

ORDOVICIAN

The principal difference between the Garber and the Oklahoma City pools is in the extent and sharpness of the buried Ordovician hill. In Garber pool the flatter part of the Arbuckle hill covers approximately 560 acres, as compared with about 1,500 acres in the Oklahoma City pool. Therefore, the area of "Siliceous lime" production in the Oklahoma City pool will probably be three times that of the Garber pool. The Arbuckle section ("Siliceous lime") at Oklahoma City is represented by very finely crystalline, hard, light brown dolomite very uniform in composition. Production seems to come from three or four separate horizons which are in the dolomite 300-500 feet below its top. Gravity of the "Siliceous lime" oil varies from 38° to 41° Bé. The average temperature of the well is 72° F. if oil alone is being produced. The temperature increases with the appearance of water, reaching a

maximum of 110° F. in a few wells. The maximum initial production of the "Siliceous lime" wells has been 950 barrels per hour, open flow, in the Indian Territory Illuminating Oil Company's Fuzzell No. 1 (SW. cor., NW. ¼, Sec. 19, T. 11 N., R. 2 W.). The first 250 feet exhibits the least saturation, principally because that section is represented by very tight dolomite. From 250 to 500 feet in, the Arbuckle section is saturated with oil, but only softer zones are sufficiently porous to produce. These softer zones may be correlated, and if this is the final conclusion after further development, the producing horizons may represent minor unconformities within the "Siliceous lime" itself. At least in the first pay zone the water level has been established on the south end of the field in the Indian Territory Illuminating Oil Company's Fee No. 1, S. Bodine No. 1, and Hemming No. 1, the Sinclair Oil and Gas Company's Stamper No. 1, and Shell Petroleum Company's Petty No. 2, all shown on the subsurface structure map (Fig. 2) by double circles. The Sinclair Oil and Gas Company's Stamper No. 1 was drilled deeper and a very large increase in oil was found at 430 feet in the "Siliceous lime," flowing 10,000 barrels natural, but that production has rapidly declined with large increase of water, which may be flooding from the first pay zone. The final determination of the Ordovician dolomite-limestone has not been made. Paleontological evidence places the upper part of the dolomitic section in the "lower Simpson" or "upper Arbuckle" of the Arbuckle Mountain section, with its contact with the true Arbuckle as yet not known. According to F. A. Bush:[1]

> The fossils obtained so far are few and poorly preserved. Also they are not particularly diagnostic in serving to differentiate between the Simpson and Arbuckle formations. They indicate, however, that the producing dolomite is below the massive sands of the Simpson. Inasmuch as the dolomite-limestone section above the massive sands is known as the "Simpson lime," a field term entirely, it is probably better for the dolomite section at Oklahoma City to be known as Arbuckle, or "Siliceous lime", in order to avoid confusion, although it may be lower Simpson dolomite section. The contact between the Simpson and Arbuckle formations in the Arbuckle Mountains is locally determined with ease but in some localities difficult to place. This condition may persist in the subsurface, for throughout the general Oklahoma area the contact between the two formations is very sharply marked. The drill passes from sand of probable Chazy age into dolomite of Canadian age. However, at Oklahoma City a dolomite of lower Simpson or upper Arbuckle, which is absent in the general subsurface, lies beneath the Simpson sand series.

If such shall be the final conclusion, then it may be possible that the section of Arbuckle producing in Oklahoma City pool has been

[1]Personal communication.

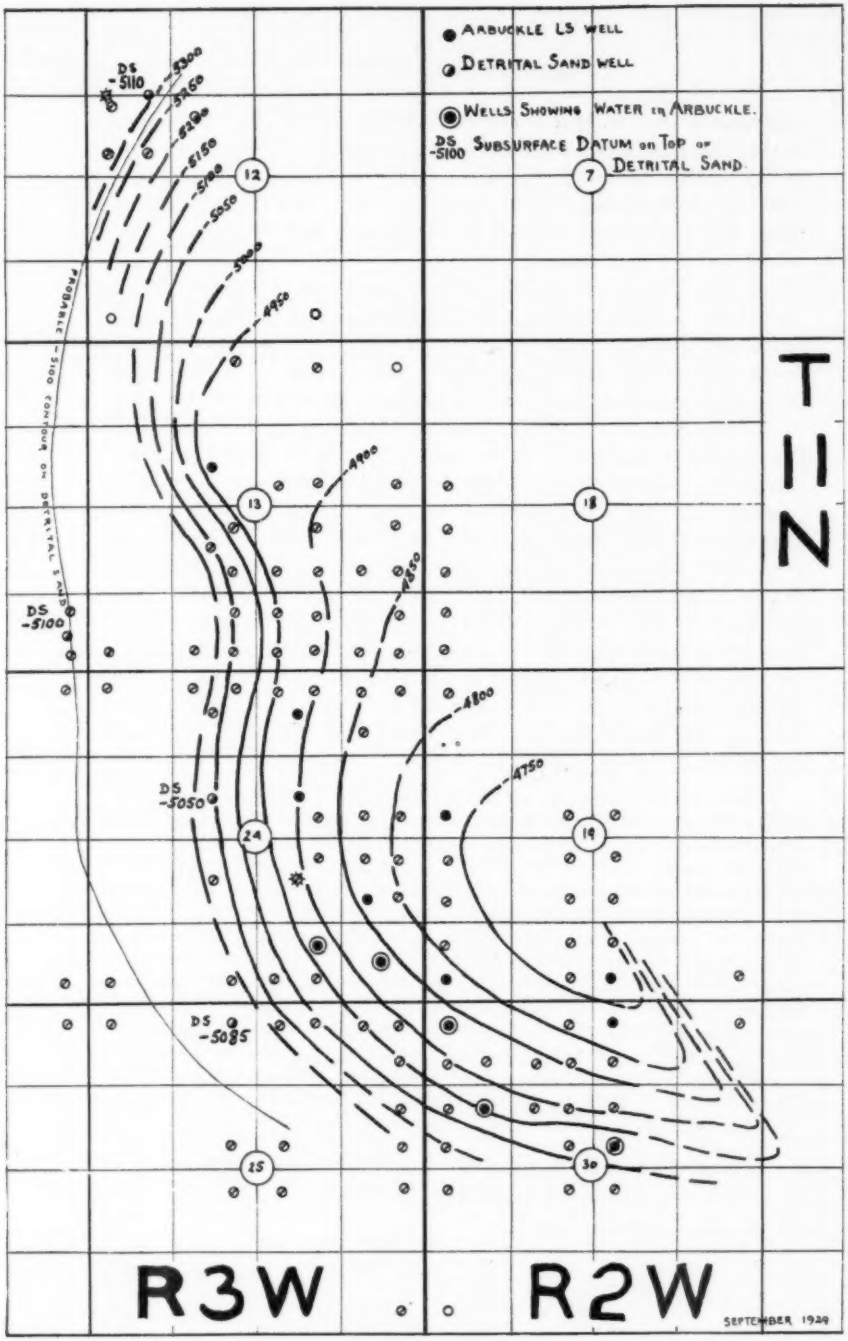
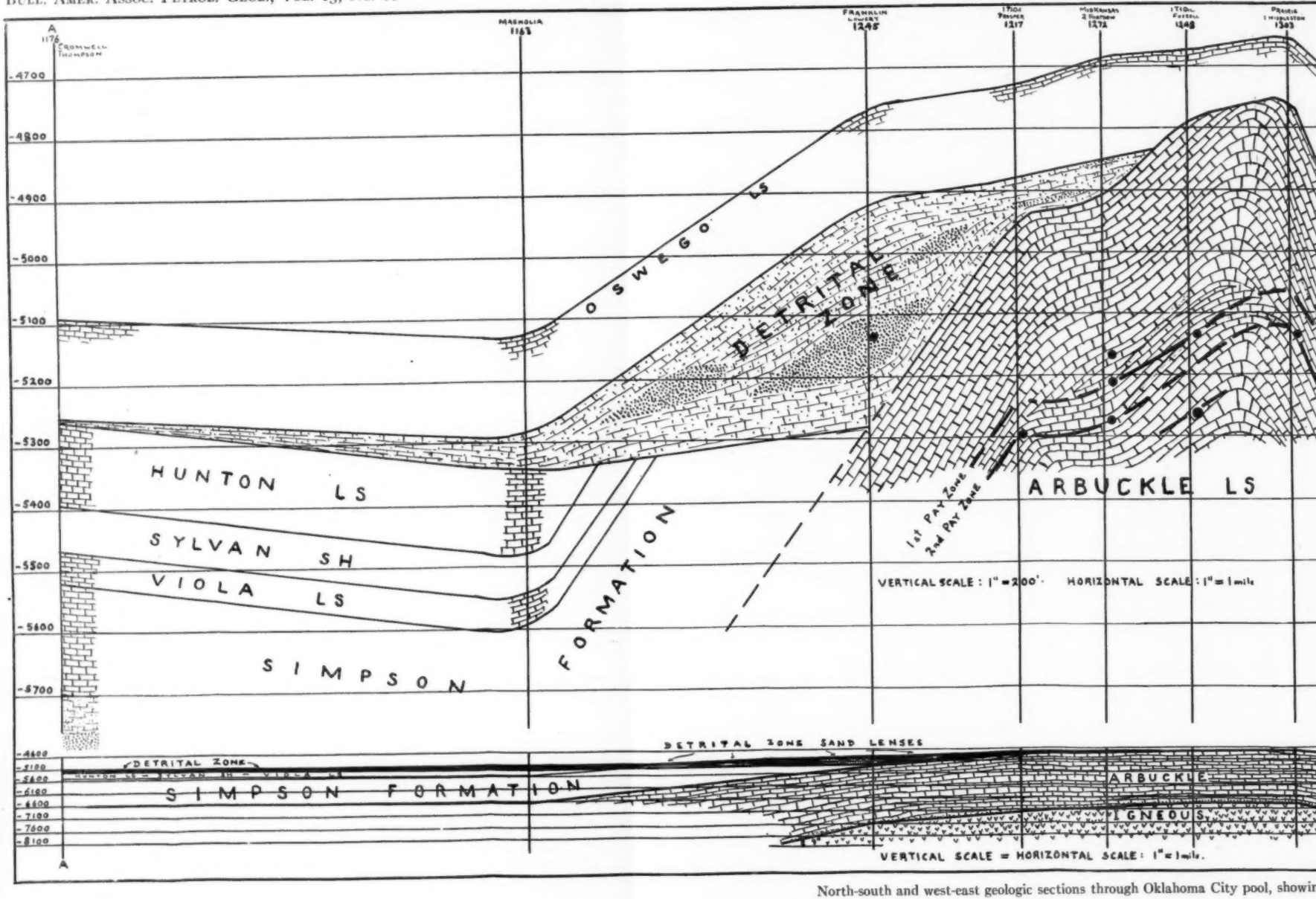
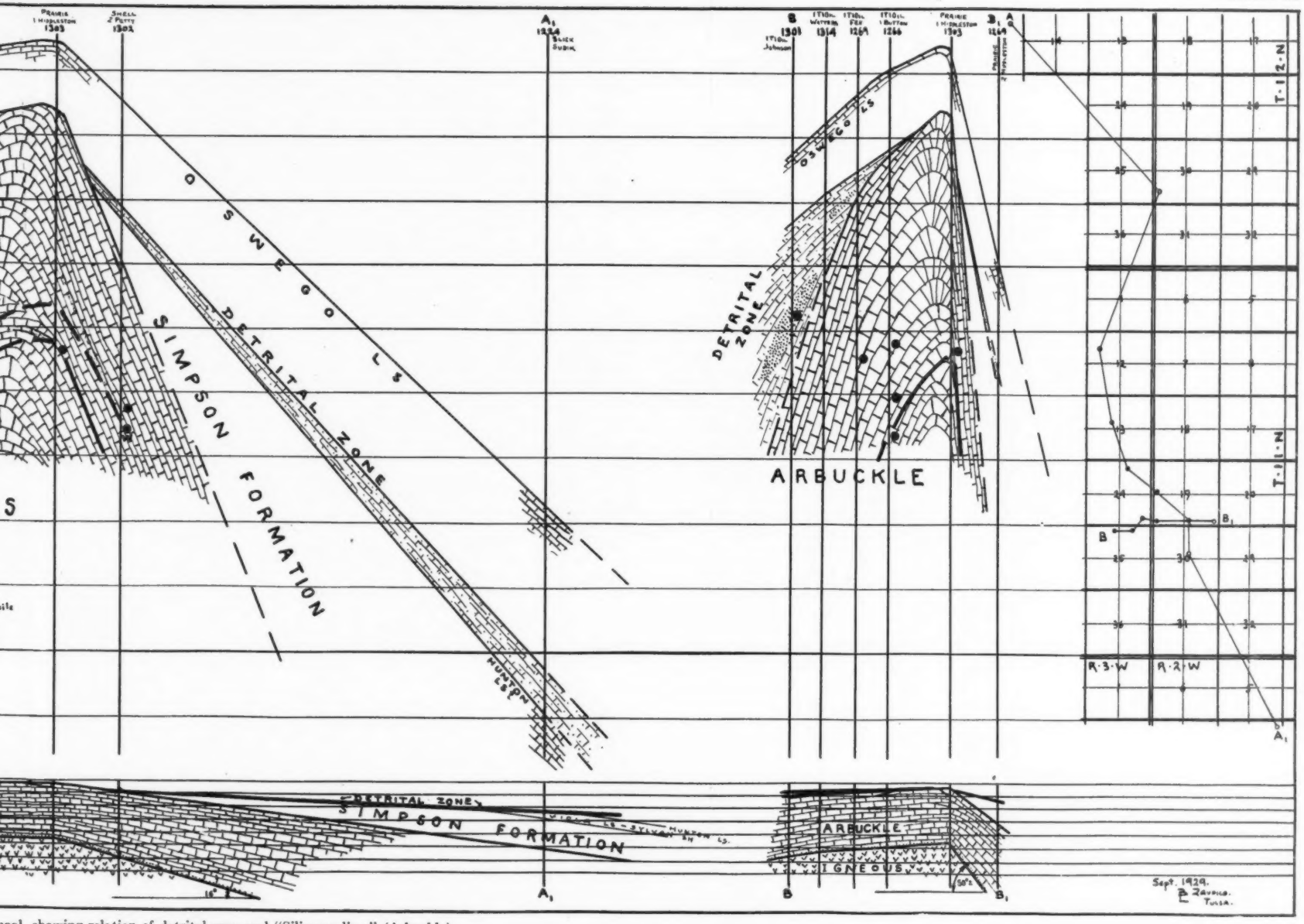


FIG. 2—Subsurface structure map of Oklahoma City pool, contoured on top of Arbuckle limestone. Contour interval, 50 feet. With of area, 2½ miles.



North-south and west-east geologic sections through Oklahoma City pool, showin



pool, showing relation of detrital zone and "Siliceous lime" (Arbuckle).

entirely eroded in the Garber pool, since that field has only 1,200 feet of Arbuckle section.

The oil very probably originated in the Arbuckle limestone proper, there being sufficient life in the Ordovician. Diatoms (naked forms), protozoa, algae, and mollusca probably furnished most of the animal matter. It is difficult to estimate at this time the recovery per acre from "Siliceous lime." In the Garber pool, where production from the "Siliceous lime" was obtained only from the upper few feet of the Arbuckle section, recovery per acre (from "Siliceous lime" only) has been about 25,000 barrels from Sinclair's Belveal 3 wells (NE. ¼, NE. ¼, Sec. 24, T. 22 N., R. 4 W.), about 50,000 barrels from Sinclair's Hartley 4 wells (W. ½, W. ½, NW. ¼, Sec. 18, T. 22 N., R. 3 W.) and probably 75,000 barrels from the Shell's Schroeder west 80-acre tract (W. ½, SW. ¼, Sec. 18, T. 22 N., R. 3 W.). Also the upward migration of oil in the Garber pool has been a major factor, thus reducing the reserves in the Arbuckle proper, not only by filling the reservoir sands (Layton and Tonkawa), but also by saturating less porous intermediate beds from which recovery is not feasible.

DETRITAL ZONE

The profile of the buried Ordovician hill, shown on the geologic section (Plate 16), exhibits sharp south (16°±) and east (50°±) dips, with much gentler north (9°±) and west (10°±) dips. Accordingly, the sedimentation processes up to Lower Pennsylvanian time favored the west and north flanks of the structure for accumulating a thick section of secondary Simpson sand (detrital) zone sand, which on the east and south flanks was probably deposited over a very large area and is consequently very thin. The flatness of the west and north flanks was most important in allowing the primary Simpson sand body, which was being eroded from the top of the structure, to be re-deposited as such with practically no impurities, thus forming a reservoir rock of primary importance. The extent of this secondary Simpson lense is yet undetermined, but its present flatness from the Coline's Olds No. 1 (center SE. ¼, NW. ¼, Sec. 24, T. 11 N., R. 3 W.) to Hall and Briscoe No. 1 (SE. of center, Sec. 14, T. 11 N., R. 3 W.) indicates a width of about 1 mile and a length of about 3½ miles. The cumulative recovery per acre from the secondary Simpson will depend entirely on the thickness of the sand body, its west dip, and the presence or absence of water. The non-sandy phase of the detrital zone, amounting at this time to as much as 250 feet in thickness, is lithologically greenish-gray, sugary dolomite very thor-

oughly mixed with green shale and a considerable amount of sand, with large frosted round quartz grains that are found throughout the detrital zone. In places the dolomite is coarsely crystalline. The detrital sand (secondary Simpson) is composed of fairly regular, medium to coarse, heavily frosted, rounded quartz grains, with few very large grains, the sand being cemented with dolomitic material. The gravity of the oil from the detrital sand ranges from 39° to 44° Bé., slightly higher than the oil from the "Siliceous lime." The initial production from the detrital sand has ranged from 5,000 to 20,000 barrels per day in the wells completed to date.

CONCLUSIONS

Undoubtedly a pool of primary importance has been uncovered near Oklahoma City, which may eventually prove to be the largest individual producer in Oklahoma. The proration of runs in the future will serve not only to reduce the current production, but also to increase the cumulative recovery from "Siliceous lime" by delaying flooding.

The foregoing views have been expressed with the knowledge at hand on September 1, 1929. As in any new pool, future developments may alter the present interpretation very considerably.

BASIL B. ZAVOICO

TULSA, OKLAHOMA
September 13, 1929

DISCUSSION

SECONDARY GYPSUM IN DELAWARE MOUNTAIN REGION

In the August, 1929, issue of this *Bulletin*, King and King in discussing the stratigraphy of trans-Pecos Texas mentioned an occurrence of gypsum near the base of the Delaware Mountain formation on the west side of Salt Flat near Dos Alamos, Hudspeth County. Their statement that "the gypsum member suggests a retreat and readvance of the seas, and thus confirms the existence of an unconformity at the base of the Delaware Mountain sandstone" implies that they interpret this gypsum to be a primary sedimentary deposit.

Several other geologists have in recent years reported the finding of "bedded gypsum" adjacent to the Salt Flat and south of the New Mexico line in the Bone Springs limestone, the Delaware Mountain sandstone, and the Capitan limestone. In places the gypsum is reported to occur in beds several feet thick, but more ordinarily in seams less than two inches thick interbedded with laminated limestones and sandstones. The idea has prevailed that these gypsum deposits are of primary sedimentary origin.

My interpretation is that most of the gypsum found at the margin of the Salt Flat is of secondary origin, resulting from the seepage and evaporation of ground water highly charged with sulphates and other salts. Exceptions are the Castile gypsum near Seven Heart Gap and the Yeso gypsum near Wilkerson Wells in New Mexico.

Thinly laminated interbedded gypsums, limestones, and sandstones are very common in the Bone Springs limestone and the Delaware Mountain sandstone in the southern part of the Delaware Mountains and elsewhere around the Salt Flat. Gypsiferous outcrops occur, most commonly ranging from a few feet to 200 feet above the level of the Flat, but some are found as high as 1,000 feet. Swelling of beds has ordinarily occurred where the outcrops are gypsiferous, resulting in abnormally steep dips which do not persist far beneath the surface. At a few localities, such as the ridges north of the Jones ranch house and the bluffs west of Dos Alamos, beds of secondary gypsum several feet thick have accumulated, forming low benches which have the deceptive appearance of being interbedded with heavy limestones.

The gypsiferous material found in intimate association with Permian sediments of this locality is commonly soft, earthy, and pulverulent, and occurs in diagonal veins as well as in seams parallel with the bedding. It is unlike the common Permian gypsum deposits of the Basin. I see no reason for presuming that its origin was very different from that of the Bolson gypsum of the Salt Flat, which was through the recent evaporation of gypsiferous ground and surface water.

C. L. MOHR

INDIAN TERRITORY ILLUMINATING OIL COMPANY
BARTLESVILLE, OKLAHOMA
August 24, 1929

STUDIES IN DIFFERENTIAL COMPACTION—A REPLY

If it were not for the possible influence of differential compaction on later rock deformation, it would perhaps be best to disregard the recent short discussion by L. L. Foley.[1] However, since an unanswered criticism may leave a wrong impression of its value, and since the whole problem of the significance of differential compaction deserves further study, this brief reply has been written.

Unfortunately, Foley's discussion is entirely based on the assumption, "in the experiments of Nevin and Sherrill, it appears that the hill was covered by the first pouring of sediments which were allowed to settle." This is followed by, "If their hard object represents a buried hill, their experiment simulated the deposition of 100 feet or more of sediment over-night. If their experiment simulates normal deposition, the hard object represents a small pebble." It is difficult to see how such an assumption could have been obtained from the original paper.

The very fact that level markers could be deposited immediately above the hill means that the sediments surrounding the hill had reached an equilibrium. This can not be obtained by as few as two pourings of thin, clayey soup. In fact, it generally took about two weeks of daily pourings and settling, before a level marker could be deposited above the hill. A glance at Plate 3, Figure 6, shows approximately fifteen recognizable additions before the first level marker (*A*, first dotted line) was deposited.[2] Moreover, the sediment was not permitted to heap up over the hill while the section around the hill was being formed.

Regardless of how many pourings were necessary to secure equilibrium around the hill, once this was obtained and a level marker deposited above the hill, any folding of it would be due to the weight of later overlying sediments. The analogy to a small pebble or to 100 feet of sediment over-night is, of course, incorrect.

The purpose of the experiments was to collect some data on the attitude of compaction folds and their possible influence in guiding later deformation. To clear up any misunderstanding, the following conclusions of general application are repeated:

1. Certain essential conditions must be fulfilled before differential compaction becomes effective. When these conditions are met, a compaction fold must result.

2. A compaction fold has in it certain inherent characteristics which are sufficiently different from those of any other type of folding to make it recognizable, and these same characteristics make it possible to detect the influence of compaction in many folds which owe a considerable part of their deformation to other factors.

[1]L. L. Foley, "Discussion of Studies in Differential Compaction," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), pp. 1074-77.

[2]C. M. Nevin and R. E. Sherrill, "Studies in Differential Compaction," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), pp. 1-22.

3. Although differential compaction, unaided by other forces, *may* result in the formation of a fold, its rôle of greatest importance is directive, and in this rôle it may determine the subsurface attitude and the surface reflection of folds which owe a large part of their deformation to forces of a very different nature.

Foley's discussion seems to be on the amount of differential compaction, a feature which has been covered by Hedberg's experiments,[1] and one with which our paper is not directly concerned. Undoubtedly the experimental evidence presented is weak in that a proper allowance could not be made for the relative size of natural compaction folds, or for the geologic time factor. However, it is to be hoped that the conclusions drawn in the original paper will be tested in the field and that some constructive criticism will result.

C. M. NEVIN and R. E. SHERRILL

ITHACA, NEW YORK
September 4, 1929

BARRIER REEFS IN WEST TEXAS BASIN

I certainly agree with Mr. Lloyd on the reef character of the Capitan limestone as recently described by him in this *Bulletin*.[2] As a matter of record I wish to mention my papers[3] delivered at conventions of this Association in 1925 and 1926, especially inasmuch as Mr. Lloyd gives several other references on this subject. In my paper at the Wichita meeting (1925) I contended that the Vidrio series of Marathon and the Capitan series of New Mexico were identical and constituted the barrier reefs which separated the great salt pan of the West Texas basin from the open sea at that period, and that these dolomites consequently graded farther basinward into the anhydrites and finally the rock salt deposits of the Great Salt Basin. I elaborated further on this again in Dallas at the 1926 convention. These papers were never published because of the press of other work.

W. A. J. M. VAN WATERSCHOOT VAN DER GRACHT

FELDBACH, STEIERMARK, AUSTRIA
August 16, 1929

[1] H. D. Hedberg, "The Effect of Gravitational Compaction on the Structure of Sedimentary Rocks," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 1035-72.

[2] E. Russell Lloyd, "Capitan Limestone and Associated Formations of New Mexico and Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 6 (June, 1929), pp. 645-58.

[3] W. A. J. M. van der Gracht, "Suggestions Concerning the Probable Subsurface Structure of the High Plains of Western Texas, as Deduced from Observations on the Surface in Trans-Pecos Texas," unpublished manuscript read before the tenth annual meeting of the American Association of Petroleum Geologists at Wichita, Kansas, March, 1925.

———, "Source Rocks of Petroleum Developed in a Salt Sequence, Illustrated in Particular by Conditions in the West Texas-Oklahoma-Kansas Salt Basin," *ibid.*, eleventh annual meeting, Dallas, Texas, 1926.

ORIGIN OF *EN ÉCHELON* FAULTS

Link's recent article on "*En Échelon* Tension Fissures and Faults,"[1] and the interesting discussions of it, clearly indicate the present lack of agreement on the origin of the well developed *en échelon* faults of northern Oklahoma. The purpose of the present discussion is to call attention to some of the more apparent objections which may be offered to the theories which have been advanced. This is done in the hope that it may lead to further discussion on the part of those most familiar with the geology of this area, and, possibly, open the way to a general acceptance of some one of the current theories or else to a final rejection of them.

Any acceptable theory for the origin of these faults, as for any other structural feature, must, in the first place, be mechanically flawless, and, secondly, be adaptable to all the known geological conditions in the area.

No one seems to doubt that lateral slipping movements in the basement complex, as assumed in Fath's well known and widely applied theory,[2] would normally result in *en échelon* folds and faults in the overlying blanket of sediments. That such movements actually did occur and did form the faults of northern Oklahoma has been questioned by Powers,[3] Link,[4] myself,[5] and others. Among the many difficulties encountered in attempting to apply Fath's mechanism to this area, the following seem outstanding: (1) the main Ouachita thrust, which is usually accepted as having caused the assumed movement in the basement complex, antedates the faults; (2) the failure of the faults to increase either in number or displacement toward the assumed thrust, (3) the close relation between the trend of the *en échelon* fault zones and the strike of the outcropping Pennsylvanian formations.

As an alternative hypothesis, Link, from observation and experiment, suggests that these *en échelon* faults owe their direction and alignment to incipient *en échelon* fissures; and the alignment of the incipient fissures is the result of simple tension at right angles to the trend of the fault zones. This suggestion meets with many objections, several of which were brought out in the discussion of Link's paper and need not be repeated here. The one outstanding difficulty in accepting Link's suggestion seems to me to lie in the question of *what determines the orientation of the individual fissures?* If incipient tension fissures are not at right angles to the direction of tension, or at least approximately so, in what direction will they trend? Can we assume they will all trend in the same general direction, and, if so, what is the basis for our assumption? In Figure 4 of Link's paper why should any more stag-

[1]Theodore A. Link, "*En Échelon* Tension Fissures and Faults," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 6 (June, 1929), pp. 627-43.

[2]A. E. Fath, "The Origin of the Faults, Anticlines and Buried 'Granite Ridge' of the Northern Part of the Mid-Continent Oil and Gas Field," *U. S. Geol. Survey Prof. Paper 128-C* (1920), pp. 75-84.

[3]Sidney Powers, "Structural Geology of the Mid-Continent Region: A Field for Research," *Bull. Geol. Soc. Amer.*, Vol. 36, (1925) p. 392.

[4]Theodore A. Link, *op. cit.*

[5]R. E. Sherrill, "Origin of the *En Échelon* Faults in North-Central Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 1 (January, 1929), pp. 31-37.

gered breaks, if developed, trend toward the upper right hand corner of his diagram than toward the upper left hand corner? In north-central Oklahoma, the individual faults, almost without exception, trend northwestward. Does not this fact necessitate, or at least strongly indicate, that some factor other than simple tension perpendicular to the fault zones must be taken into account? To me, it seems most logical to believe that this directive factor was a general tension and shear resulting from torsion. As Lahee says, "Torsion would affect almost all strata subjected to upfolding or downfolding"[1] and torsion involves forces of tension, compression, and shear. As pointed out in an earlier paper,[2] the present attitude of the Pennsylvanian strata of north-central Oklahoma clearly demonstrates that the forces responsible for the present regional dip exerted a regional torsional stress on the formations. Link calls attention to the difficulty of visualizing regional torsion. Is it not more difficult to visualize regional northwest breaks as caused by east-west tension alone?

In general, then, it seems that from the standpoint of mechanics, *en échelon* faults *trending uniformly in the same direction* may easily be explained either by Fath's conception of lateral slipping movements in the basement complex, or by a combination of simple tension with the tension and shear due to torsion in the sedimentary formations. In attempting to apply Fath's mechanism to the faults of Oklahoma we encounter the objections previously mentioned. Would it not be well, then, carefully to consider the possibility of applying the alternative hypothesis to this region?

R. E. SHERRILL

UNIVERSITY OF PITTSBURGH
PITTSBURGH, PENNSYLVANIA
September 12, 1929

[1]Frederic H. Lahee, discussion of Link's paper, *op. cit.*, p. 638.

[2]R. E. Sherrill, *op. cit.*

REVIEWS AND NEW PUBLICATIONS

Paleontology. By EDWARD WILBER BERRY. McGraw-Hill Book Company, Inc. (New York and London, 1929). 392 pp., including glossary and index; 175 figures. Price, $3.50.

This publication is written as a textbook, and it is a very welcome addition to the limited number of texts on paleontology. It represents the results of many years of study and of teaching by the author in Johns Hopkins University.

The subject is treated in eleven chapters, an introductory one and ten others, each of which deals with a single phylum, except Chapter V on the general subject of worms, including flat, round, wheel, annulate worms. The chapter headings are as follows: Protozoa, Porifera, Coelenterata, Worms, Echinodermata, Bryozoa, Brachiopoda, Mollusca, Arthropoda, and Vertebrata. This grouping follows general usage, except that Bryozoa and Brachiopoda are commonly placed as classes under Molluscoidea.

The introduction gives the more common methods of estimating the length of geological time, but omits the rate of recession of falls and the rate of erosion of post-glacial valleys. It includes a geological time-table and a discussion of the classification of animals. Under Protozoa, *Foraminifera* and *Radiolaria* are treated satisfactorily, though no idea is given of their importance, nor of the extended use to which they have been put in determining horizons from well cuttings. The treatment of Porifera is too brief, and it lacks illustrations of some of the more important types of sponges. Sponges are widespread, fairly common, and are good to mark horizons, especially in some parts of the Ordovician. In the group of the Coelenterata too brief a discussion is given of the *Anthozoa*, and more illustrations are needed under each of the first three sub-classes. The chapter on worms is only 1½ pages in length and has no illustrations. The common Silurian *Arthrophycus* is not mentioned, nor is any mention made of Conodonts, which are recognized as important markers for certain horizons in Middle and Upper Paleozoic formations. The seven classes under the phylum Echinodermata are treated satisfactorily, except that illustrations of the more common generic types would be helpful. Four of the five classes of Mollusca are adequately discussed, but there are no illustrations for *Amphineura* or *Scaphopoda*. The fifth class, *Gastropoda*, has not been given consideration which is at all proportional to their importance as fossils. The evolution of the *Cephlapoda* is particularly well wrought out and it is well illustrated. The characterization of the various classes of the Arthropoda is good, and especially so is the part dealing with the adaptation of the *Trilobita*. The chapter on Vertebrata is particularly well handled and the classes under this phylum are well illustrated.

Excellent graphic tables are included to show the range and relationships of the different groups under Echinodermata, Brachiopoda, Cephalopoda,

Arthropoda, Eurypterida, Pisces, Amphibia, Reptilia, Camels, Horses, Proboscidea, Rhinoceroses, and Primates. Also, the range of most of the subgroups is given in the text. A printed classification at the head of each chapter would help to make relationships still clearer. The glossary is a very welcome addition, and it will be greatly appreciated by students.

A few errors have crept in, such as calling *Phoronis* and *Balanglossus* worms. Theca is used for hydrotheca of a hydrozoan. Polian vesicles are omitted from the water-vascular system of asteroids and echinoids. A few of the definitions might be stated more exactly, such as umbilicus, siphuncle, pallial line, and hydrospires. The print and paper are good and the illustrations are clear. The writer plans to use parts of this book as a text for an advanced class in paleontology.

CHARLES E. DECKER
Professor of Paleontology

UNIVERSITY OF OKLAHOMA
NORMAN, OKLAHOMA
September 2, 1929

"Geophysical Methods of Prospecting, Principles and Recent Successes." By C. A. HEILAND. *Quarterly of the Colorado School of Mines* (Golden), Vol. 24, No. 1 (March, 1929). 163 pp., 65 figs. Price, $1.00.

The purpose of this paper is not only to describe the fundamental principles of geophysical prospecting, but mainly to demonstrate the actual extent and recent successes of geophysical methods on this continent. The table of contents comprises the following headings: introduction, significance of geophysical prospecting, possibilities and limitations; classifications of geophysical methods; gravity methods; magnetic methods; radioactive methods; geothermal measurements; seismic methods; electrical methods; underground geophysical prospecting; depth reached with geophysical methods; cost of geophysical work; statistical section containing a list of consulting geophysical companies and geophysicists, a list of manufacturers of geophysical instruments, a statistical review of recent geophysical activities in the United States, Mexico, and Canada, and a list of counties in the United States, provinces in Canada, and states in Mexico in which geophysical work has been done.

This pamphlet contains a mine of information, particularly reference material, and the reviewer himself finds it useful. An elementary understanding of the various methods can be gained from it by any one who has a modest knowledge of physics, but the oil man and geologist may find the exposition of the various methods somewhat involved. It succeeds, however, in giving a most vivid picture of the magnitude and extent of geophysical prospecting in this country at the present time, although the picture of the success of the methods is painted slightly too optimistically.

The following detailed criticism is pertinent within the fields with which the writer is especially familiar:

Page 7. The possibility of the location of petroleum directly by any gravity method, no matter how close to the surface, is doubted by the reviewer.

Pages 27, 28, 29. The gravity minima at Orange and Welsh much more probably represent deep salt domes than lows in the pre-Tertiary surface.

Boling has been a productive dome for several years.

The comments on Markham and Damon Mound are reversed.

Page 31. Boling, the richest-known sulphur deposit in the world, is omitted from the list of the sulphur domes.

No. B. 9 and E. 36, Gulf Sulphur and Big Hill (Matagorda) are identical.

No. E. 47, Raccoon Bend, should be classed under "A, Presence of dome not yet proved."

Group II, "Gulf Coast salt domes discovered by torsion balance" includes one long-known dome (Davis Hill), two prospects which were never generally accepted as probable salt domes (Dickinson and Youngs Ranch), and others which are not generally accepted definitely as probable domes.

Page 32. Many of the domes listed are of doubtful existence. No. A. 4, Ferguson (Clay Creek or Gay Hill) was discovered on the basis of surface geology, not seismic work, although it was checked by the seismograph before it was drilled.

No. A. 5, Hankamer is a dome (now productive) discovered with the torsion balance, not the seismograph, and was condemned by the latter.

No. B. 17, Boggy Creek was discovered by geological work and core drilling, not geophysical work.

No. C. 37, Bayou Henry was the temporarily successful attempt to attract and hold the attention of rival scouts to an area where there was nothing of interest. It was soon checked and condemned by all companies.

No. C. 46, Egan is a torsion-balance prospect.

Page 36. The maxima over many salt domes are due not only to the effects of the cap rock but also to the upper part of the salt. On some of the shallowest domes, the top of the salt is 0.2-0.3 heavier than the surrounding sediments.

"The coastal effect and the effect of the pre-Tertiary land surface" should not be stated so dogmatically. The reviewer doubts very much that they are an explanation of the observed effects. The explanation may more probably lie in the conformation of the salt series in depth.

Page 37. The question of maximum vs. minimum in connection with the salt domes and oil fields seems to the reviewer very plainly to be the effect of differences in form, depth, and shape of the salt core (and in the shallower domes, of the cap rock).

Page 43. Typographical errors: Northam should read Wortham, and Leguin should read Seguin.

The excellent work with the torsion balance on the Mexican salt domes is not mentioned. In figures 19 and 20, the legends are interchanged.

Page 60. Reconnaissance prospecting for salt domes in the Gulf Coast is and has been done extensively with the torsion balance. At present almost half of the torsion balances of this country are in the Gulf Coast, most of these on reconnaissance for salt domes.

Pages 59-72. A somewhat more optimistic impression of the success of the magnetometer will probably be obtained from these pages than the writer feels is warranted.

Page 82. The extensive series of measurements by the American Petroleum Institute, unpublished as yet, but generally known to the oil fraternity, has been overlooked.

Page 85. The suggestion that a supersensitive seismograph with large amplification will permit a considerable reduction in the amount of dynamite does not work out in practice, as the micro-ground unrest puts a very definite limit to sensitivity and amplification.

Pages 92-93. The same comments may be made about Gulf Sulphur, Big Hill (Matagorda), Raccoon Bend, and Davis Hill.

Page 94. The same comments hold for this list as for the list on page 32. It is a very uncritical list of supposed domes discovered by the seismograph.

Page 96. The Geophysical Research Corporation was organized in 1925.

Page 128. The depths reached by the torsion balance and seismograph are much understated. It is size vs. depth which counts with the torsion balance. In many places, the torsion balance seems to be mapping batholiths in the basement whose relief may be several miles and the surface of the basement itself may be at a depth of 10,000 feet. Salt domes which do not rise to within 4,000 feet of the surface probably can be mapped; at least, we think we are mapping salt domes which may not rise within 6,000 feet of the surface. The seismograph companies think that they are working well below 5,000 feet (15,000 feet in California; 12,000 feet in southern East Texas).

The faults and deficiencies of this paper arise chiefly because its scope is so very comprehensive and because it seemingly was rather hastily written. It falls just short of being a most excellent paper. The reviewer recommends it to any one who wishes to get a vivid picture of the magnitude and extent of geophysical prospecting.

DONALD C. BARTON

HOUSTON, TEXAS
September, 1929

Die Rumanischen Erdöllagerstätten. By KARL KREJCI-GRAF. Ferdinand Encke (Stuttgart, 1929). 130 pp.

The author gives a very interesting and, as far as the reviewer is able to judge, up to date, though highly condensed, discussion of the geology of the Roumanian oil fields. He does not give technical or engineering information, but confines himself to a geological discussion of the sedimentary sequence, the structure, and the probable source and migration of the oil, thereby giving a valuable contribution to oil geology. He rightly considers Roumania an excellent field for research work.

For this reason the study of this little book (130 pages of text) is highly recommended to all petroleum geologists, even to such as may never be called upon for work in this particular region.

In the first part the author describes the oil zone, its relation to the Carpathian mountain chain, and the structure of the oil fields; the second part discusses the theoretical conclusions that may be drawn regarding the probable source of the oil, its migration, and accumulation.

Brief summary.—The Roumanian oil belt is confined to the outer edge of the Carpathian mountain chain, a continuation of the bituminous belt which borders the Alpides in general. In the basin of southern Roumania it is particularly rich, presumably on account of most favorable conditions for the deposi-

tion of source sediments. Between this and another rich spot in the north, in Galicia, lies the poorer stretch of Moldavia. Inside the loop of the Carpathians, in Transylvania, we know only gas fields.

Sedimentary sequence.—Cretaceous and older Tertiary fill, in Flysch facies, the geosyncline of the later Carpathians. The folding of the present chain falls in the Oligocene, in the later part of which considerable alternations of emergence and subsidence set in. As a consequence the facies varies continuously between fresh-water deposits, marine sediments, and desert conditions: almost every imaginable facies is represented, outside the pelagic one. Conditions grade into one another; a notable consequence is the formation of concentration basins with saline sediments and rock salt. The subsequent compression and overthrusting of the Carpathians, which reached their climax in the upper Oligocene (but continued in decreasing intensity, until well into the Pliocene) brought into contact sediments which were originally deposited at widely separated times and in different provinces. In the autochtome foreland there is considerable difference in facies in the various local basins of sedimentation which were formed during the progressive and locally variable process of folding.

Detailed correlation tables are given. Special attention is given to a discussion of the age of the salt deposits.[1]

The author comes to the conclusion that there is no doubt that the salt deposits are of upper Oligocene age, and that, after an intermediate deposition of black bituminous marine shales, another saline facies began in the Miocene, a continuation of the Schlier deposits of the Alps and the western Carpathians, but here without actual rock salt, except in Solonţu-Stanești in eastern Roumania.

Structure.—The structure of the Roumanian oil fields is tremendously complex, being the result of involution of the sediments of the foreland with the front of the thrust sheets. It is illustrated in a very condensed but somewhat complete description of the structure of the individual oil fields, with good cross sections. Space does not permit me to summarize the mass of interesting information offered. The outer edge of the thrust sheets overrides the oil belt in Galicia, cuts more or less diagonally across it in eastern Roumania, and recedes behind it in southern Roumania. A perusal of these pages and cross sections will probably inspire American geologists with respect for the problems which their European colleagues are compelled to meet here. Nothing of the kind exists in the American oil country, except, to a much milder degree, along the front of the Canadian Rockies in Alberta. Workers in the latter area will find inspiration in the analysis of these Roumanian structures.

A special feature of southern Roumania is the series of outer salt upthrusts, a string of diapiric folds, that is, anticlines in which the interior more plastic beds (salt and saline rocks) have been thrust bodily through the outer shell of younger formations. These structures comprise all gradations between normal anticlines, salt anticlines, and true salt domes. The perusal of this description is highly recommended to geologists who have to do with saline structures, either in the Gulf states or in the Paleozoic salt basins of Utah.

[1] A controversy was raised regarding this by Voitești, see *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9 (1925), pp. 1165-1206, and discussion by the reviewer.

Theoretical conclusions.—The second part of the book is occupied with theoretical deduction from the facts discussed in the first part. It treats of the subjects: oil accumulations and structure, migration, reservoir rocks, and source rocks.

Invariably the oil and gas accumulations occur in the highest parts of major deformational structures. Subject, of course, to porosity, the productivity and the separation of water, oil, and gas regularly follows even minor structural details on the major uplifts.

The juxtaposition of almost every kind of rock in the involved Roumanian structures permits a close study of the migration and accumulation of oil and gas in reservoir rocks. These latter are always pure sands, free from too much admixture of clay or marly material; porous limestones do not occur in the sequence. Accumulation occurs in every suitable contact bed, regardless of geological age or formation.

Source rocks.—After a discussion successively eliminating all other formations, the author comes to regard the uppermost Oligocene Cornu shales, black sulphurous and highly bituminous marine shales, as the exclusive source of the Roumanian oil. They occur in considerable thickness (as much as 500 meters in southern Roumania) between the saliferous horizons of the Oligocene and the Miocene. They are everywhere bituminous, evidently the product of sedimentation in quiet, probably concentrated sea water; absence of bottom life but presence of nekton and plankton remains indicate absence of oxygen in the deeper layers of water. All oil accumulations show contact of the reservoir beds, or at least close proximity to this source horizon.

Several further pages contain an interesting theoretical discussion of the general problem of petroleum genesis and source rocks, notably the necessity of migration, and also touch the great problem of the manner in which petroleum and gas may originate from bituminous source rocks. Space does not permit further discussion. I may come back to this at a later date, elsewhere, after the author has published another more general paper, which he announces, treating of the problems of oil genesis.

A bibliography of 160 books and papers accompanies the book. A good index of localities and subjects is added.

As said before, the whole is a valuable contribution to oil geology and can be recommended to every oil geologist, whether interested or not in the local problems of Roumania.

W. A. J. M. VAN WATERSCHOOT VAN DER GRACHT

HAINFELD CASTLE
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RECENT PUBLICATIONS

ARKANSAS

"Upper Cretaceous Formations of Southwestern Arkansas," by Carle H. Dane. *Arkansas Geol. Survey Bull. 1* (Little Rock, 1929). 215 pp., 29 pls., 4 figs., 1 pocket map, and 1 correlation chart.

AUSTRIA

"Zur Geologie des Thayagebietes," by E. Schnabel. *Petrol. Zeitschrift* (Berlin, August 7, 1929), Vol. 25, No. 32, pp. 1097-1100, 1 illus.

CROOKED HOLES

"Questionnaire Develops Data on Crooked Hole Problem," *Oil Weekly* (September 13, 1929), pp. 28, 91.

"Standard Drilling Report Form Suggested," *Oil Weekly* (September 13, 1929), p. 29.

"Value of Drilling Straight Holes," by Fred M. Allison. *Oil Weekly* (September 20, 1929), pp. 42-43, 52-53, 55; 1 illus.

GENERAL

"Bureau of Mines Experimental Oil Shale Plant—Construction and Operation, 1925 to 1927," by Martin J. Gavin and J. S. Desmond. *U. S. Bur. Mines* (Washington, D. C.). In preparation.

"Re-Pressuring of Oil Sands," by Gwyn Elias. *Jour. Inst. Petrol. Tech.* (London, August, 1929), Vol. 15, No. 75, pp. 428-39.

"Petroleum Research," *Bull. Amer. Petrol. Inst.* (250 Park Avenue, New York, N. Y.), Vol. 10, No. 55 (September 9, 1929). 32 pp. Contains statement of progress on projects, list of papers published or approved, and projects and personnel for coming year.

Petroleum-Vademecum (International Tables for the Oil Industry), 6th edition (1929), by Robert Schwarz. Duty-tariffs, production statistics, import and export of all countries, et cetera. Verlag für Fachliteratur Ges. m. b. H., Berlin W. 62, Courbièrestrasse 3, Vienna XIX/1, Vegagasse 4. Cloth, 252 pp. Price: M. 20; 20 S.; $5.00.

"Beiträge zür Kenntnis der Devonflora," III, by R. Kräusel and H. Weyland. *Abh. Senckenberg. Naturf. Ges.* (Frankfurt a. M., 1929), Vol. 41, No. 7, pp. 315-60, 34 figs., 15 pls.

GEOPHYSICS

Applied Geophysics in the Search for Minerals, by A. S. Eve and D. A. Keys. The Macmillan Company (New York City, 1929). 253 pp., 92 illus., bibliography and index. Price, $4.50.

Geophysical Abstracts, No. 3, by Frederick W. Lee. *U. S. Bur. Mines Information Circular 6154* (July, 1929), Washington, D. C.

OKLAHOMA AND ARKANSAS

"Some Upper Mississippian (Fayetteville) and Lower Pennsylvanian (Wapanucka-Morrow) Ostracoda of Oklahoma and Arkansas," by Bruce H. Harlton. *Amer. Jour. Sci.* (September, 1929), pp. 254-70, 2 pls.

POLAND

"Das Erdölgebiet von Mraznica in Polen," by Karl Friedl. *Petrol. Zeit.* (Berlin, September 11, 1929), Vol. 25, No. 37, pp. 1245-52, 2 maps, 2 profile cross sections.

RUSSIA

"The Geology of Datich (North Caucasus) Oil Region," by V. Dolicki. Illustrated with geologic and topographic maps. *The Azerbaidjan Oil Industry* (Russian) (Baku, 1929), No. 6-7, pp. 28-44.

"Wo und Wie sind neue Erdölfelder in der U. d. S. R. R. su suchen?"-by A. D. Archangelskij. *Petrol. Zeit.* (Berlin, September 11, 1929), pp. 1255-56, 2 maps.

TEXAS

"Oil from Cone-Domes in Texas," by Frederick W. Sardeson. *Pan-Amer. Geol.* (Des Moines, Iowa, September), pp. 118-24.

The Bureau of Economic Geology, Austin, Texas, announces the following publications:

"Geologic Map of Grayson County," by F. M. Bullard. (Text not yet ready.) Price, $0.25.

"Preliminary Map of Underground Position of Pre-Cambrian in Texas," by E. H. Sellards. Price, $0.25.

"Contributions to Geology, 1929": (a) Depositional History of the Red Beds and Saline Residues of the Texas Permian, by Charles Laurence Baker; (b) Notes on the Permian Chinati Series of West Texas, by Charles Laurence Baker; (c) The Texas Meteor of June 23, 1928, by E. H. Sellards; (d) The Paleozoic of the Pedernales River Valley in Gillespie and Blanco Counties, by Richard A. Jones; (e) The Pratt Well in Webb County, by Richard A. Jones; (f) The Pennsylvanian Ostracoda from Menard County, Texas, by Bruce H. Harlton; (g) A Yegua Eocene Delta in Brazos County, Texas, by Lyman C. Reed and O. M. Longnecker, Jr.; (h) The University Deep Well in Reagan County, Texas, by E. H. Sellards and Waldo Williams; (i) Upper Cretaceous Taylor Ammonites from Texas, by W. S. Adkins. *Bull. 2901.* Paper cover, price, $1.00. Cloth bound, price, $1.75.

"Ostracoda of the Cretaceous of North Texas," by C. I. Alexander. *Bull. 2907.* 137 pp., 10 pls. Price, $0.75.

"Stratigraphic and Structural Studies in North Central Texas," by M. G. Cheney. *Bull. 2913.* 29 pp., 8 pls. Price, $0.50.

"Taylor County Geologic Map." Published in coöperation with the American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists. Size, 45 x 45 inches. Scale, 4,000 feet = 1 inch. White paper print, $2.00; cloth print, $3.00; paper print, hand-colored, $4.00; cloth print, hand-colored, $5.00.

TRINIDAD

"Some Notes on Cretaceous Occurrences at Lizard Springs, Trinidad," by P. W. Jarvis. *Jour. Inst. Petrol. Tech.* (London, August, 1929), Vol. 15, No. 75, pp. 440-42.

"Some Notes on a Portion of the Lizard Springs Anticline," by R. H. Skelton. *Jour. Inst. Petrol. Tech.* (London, August, 1929), Vol. 15, No. 75, pp. 443-55.

AT HOME AND ABROAD

GEORGE A. WEAVER, petroleum engineer with The Pure Oil Company at Fort Worth, Texas, is the author of an article entitled "Maracaibo Basin Could Meet World Demand for Several Years," in the September issue of *Petroleum World and Oil Age*.

J. E. EATON, consulting geologist, Los Angeles, California, wrote on the "Relation of Geology to a Lot of Things—Like Wildcats, Optimism and Dry Holes" in the September number of *Petroleum World and Oil Age*.

P. B. NICHOLS is now with the geological department of the Indian Territory Illuminating Oil Company in the Oklahoma City field.

DELMAR R. GUINN has been transferred from the Amarillo, Texas, to the Roswell, New Mexico, district of the Empire Companies.

SIDNEY POWERS, consulting geologist for the Amerada Petroleum Corporation at Tulsa, Oklahoma, has an article, "Collines enterrées (Buried Hills) et champs pétrolifères du monde," in *La Revue Pétrolifère* for August 24, 1929.

J. WHITNEY LEWIS of Fort Worth, Texas, is examining oil properties in Cuba. Mrs. Lewis is with him.

HUBERT G. SCHENCK, of Stanford University, spent the three summer months in the Coalinga district, California, for the Standard Oil Company of California.

W. A. BAKER has succeeded RAYMOND LEIBENSPERGER as chief geologist of the Tampico organization of the Transcontinental Petroleum Company. Mr. Leibensperger has been transferred to Holland.

A. B. ROWLEY is now with the Peters Petroleum Corporation at Tulsa, Oklahoma.

L. A. HOLMES, geologist with the Skelly Oil Company, has been transferred to the company's El Dorado, Kansas, office.

A. V. JONES, formerly with the Marland Production Company, is associated with Merry Brothers & Perini, Fort Worth, Texas.

RALPH C. BREHM is micropaleontologist for the Producers and Refiners Corporation at Tulsa, Oklahoma.

KARL E. YOUNG is chief geologist for the Union Sulphur Company at Sulphur, Louisiana.

GEORGE V. DUNN, formerly chief geologist for the White Eagle Oil and Refining Company, has opened an office for independent work at 632 Mayo Building, Tulsa, Oklahoma.

W. H. GEIS, vice-president of the Continental Oil Company of Arizona, has resigned to become president of the newly organized Arrowhead Oil Company of California.

P. S. HAURY, district geologist for the Simms Oil Company at Midland, Texas, has been transferred to Shawnee, Oklahoma.

ANGUS MCLEOD, superintendent of the land and geological department of the central division of Shell Petroleum Corporation, Dallas, Texas, took a honeymoon trip to Europe in September.

C. E. HAMILTON is in the employ of the Sinclair Oil and Gas Company at Seminole, Oklahoma.

ELTON RHINE, in charge of the office of the Empire Companies at Shreveport, Louisiana, has moved his office to 314 Petroleum Building, Houston, Texas.

L. A. BARTON, formerly in independent consulting work at Shreveport, Louisiana, is now with the geological department of the Arkansas Fuel Oil Company, with the Shreveport office as headquarters.

J. W. PAULSEN, JR., formerly assistant chief geologist with the Petroleum Securities Company, has opened an office as consulting petroleum geologist at 721 Bank of Italy Building, Los Angeles, California.

FOREST R. REES is president of the Oil Properties Corporation and geologist for the Petroleum Royalties Company, 402-406 Atlas Life Building, Tulsa, Oklahoma.

QUENTIN D. SINGEWALD has resigned as assistant professor at the Colorado School of Mines to become assistant professor of geology at the University of Rochester, Rochester, New York, where he will have charge of the work in economic geology.

FREDERICK G. CLAPP, petroleum engineer of 50 Church Street and Bronxville, New York, who for the past six years has been concentrating on advisorship in connection with Eastern Hemisphere oil and gas developments, has decided to maintain a semi-permanent office in Paris, specializing in all matters affecting Eastern Hemisphere developments. He will continue to maintain the New York office also and, until a definite European address is assumed, Mr. Clapp can be reached through air or by cable at "Consultoil Paris."

JOHN F. WEINZIERL, of Houston, Texas, consulting geologist and geophysicist, has moved his offices to 607-608 Petroleum Building.

EDMUND JUSSEN, JR., has been appointed chief petroleum engineer of the Union Oil Company of California, succeeding A. C. RUBEL, recently appointed assistant manager of production.

H. C. GEORGE has returned to the University of Oklahoma after having made three months' investigation of underground equipment and methods in oil fields for the United States Bureau of Mines.

CAREY P. BUTCHER, who was in charge of the Continental Oil Company district geological and scouting office in San Angelo, Texas, which has been closed, has been transferred to Roswell, New Mexico.

H. D. CRIDER, Dixie Oil Company geologist, has resigned to become chief of the new geological staff of the Muskegon Development Company, the Muskegon Oil Corporation, and three other associated Michigan operating concerns. VICTOR G. HILL, assistant Michigan geologist for the Dixie Oil Company since November, 1928, has been named chief of the Michigan staff to succeed Mr. Crider.

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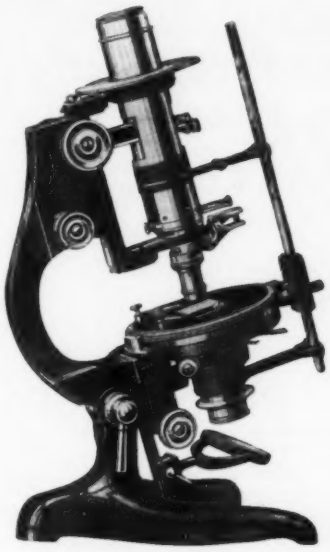

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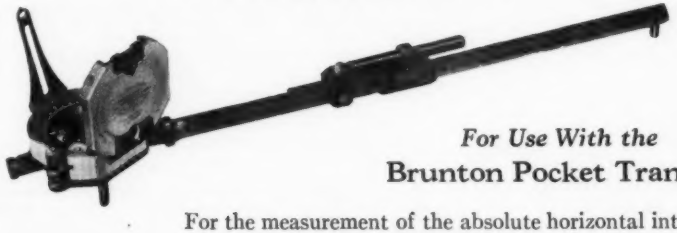

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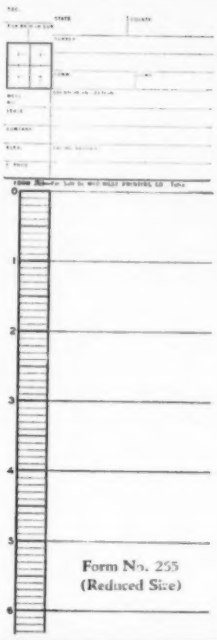

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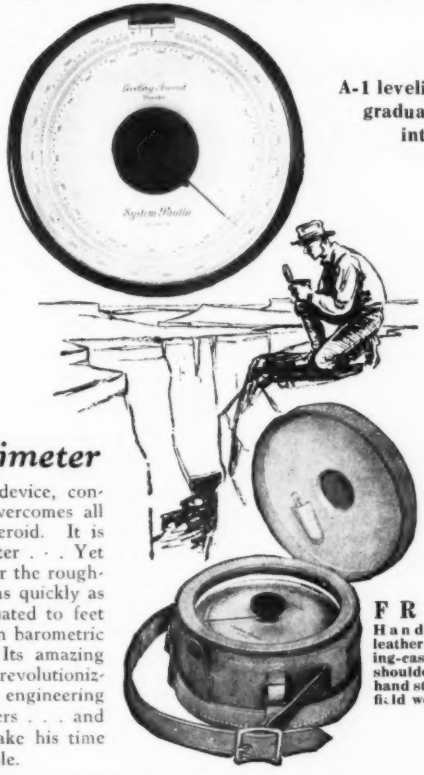

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